THE SATELLITE TVRO HANDBOOK

written & compiled by Mark Long

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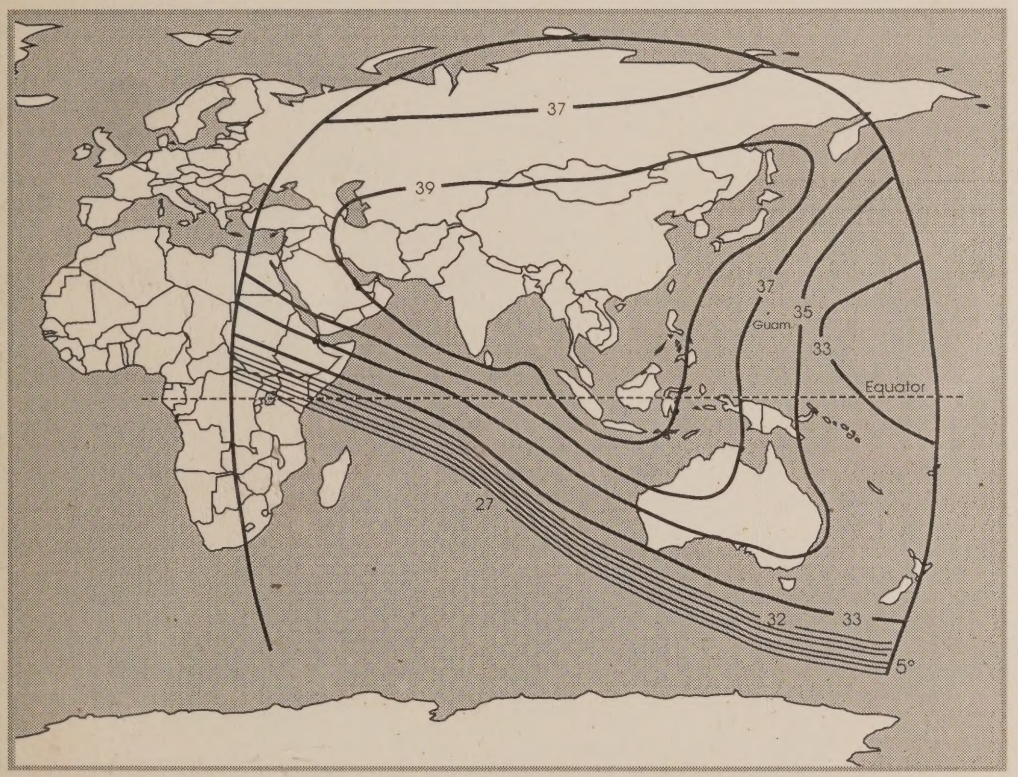

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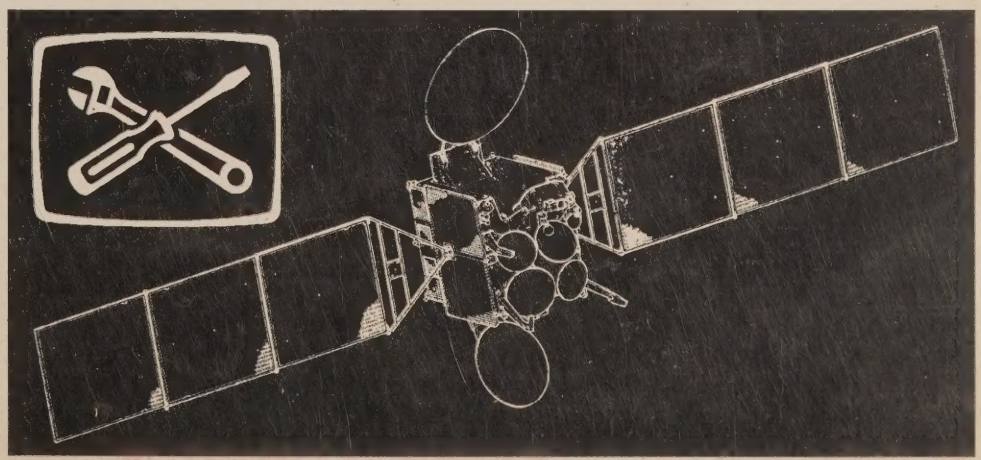

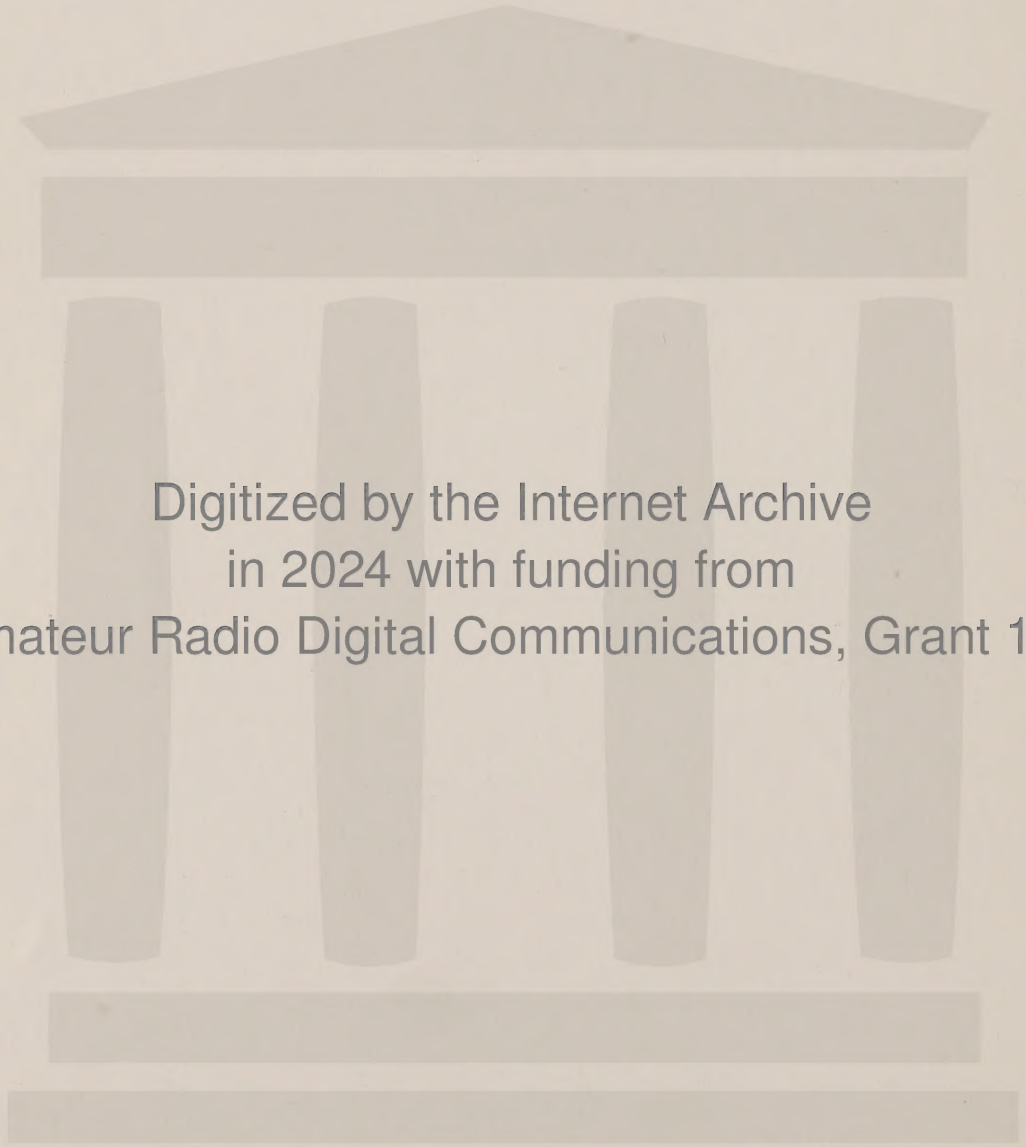

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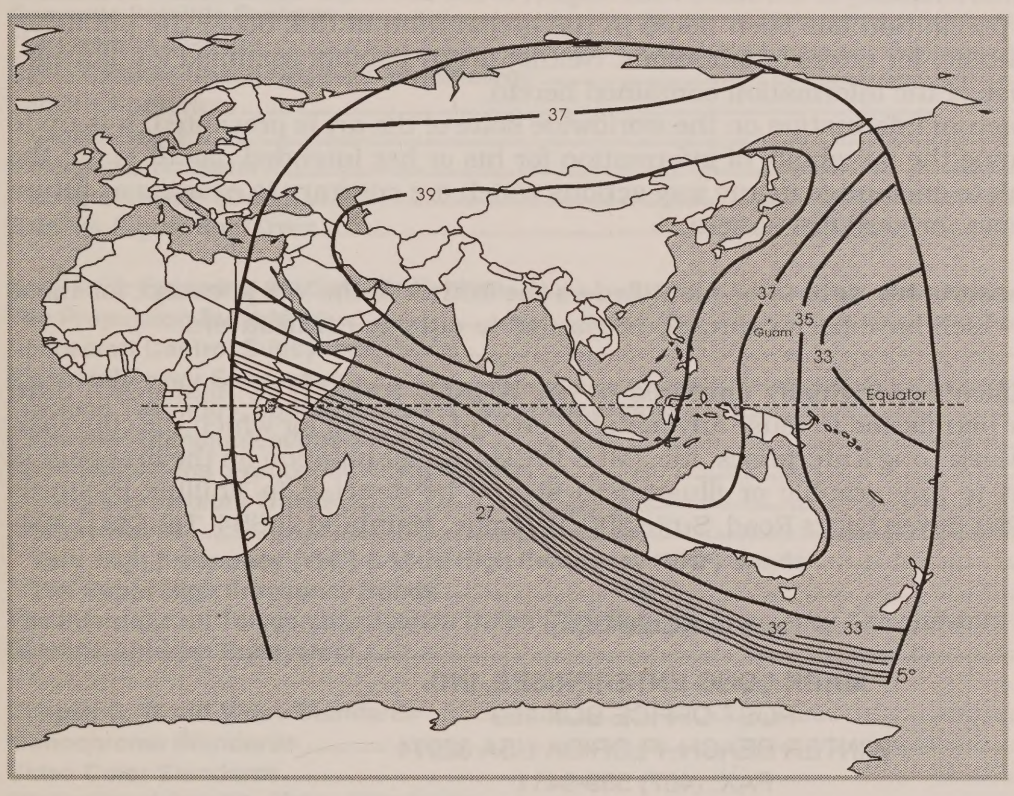

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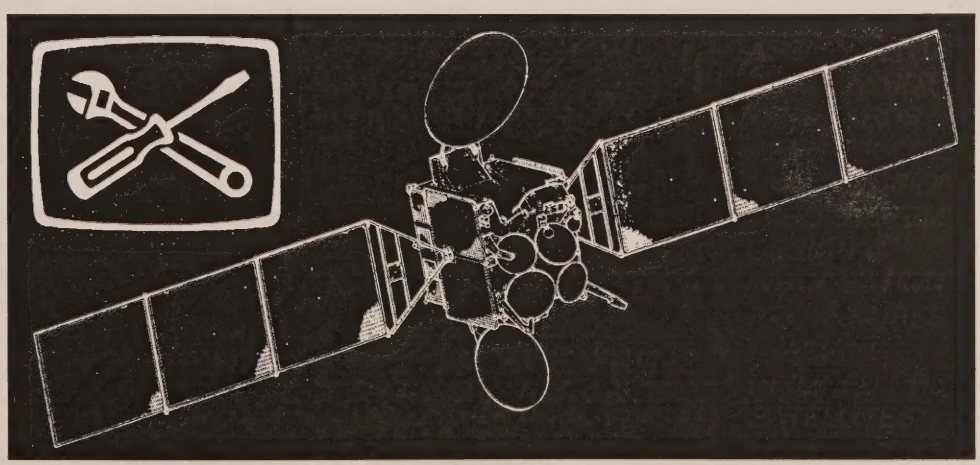

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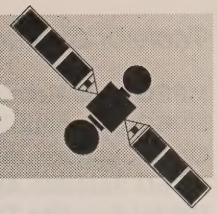

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Foreword

On June 25, 1967, for two hours twenty six nations of the world were joined together by an invisible electromagnetic grid utilizing four satellites. The London-based production, in glorious black and white, was the first-ever use of satellites to simultaneously interconnect remote corners of the world to a single programme event. The programme, appropriately entitled *"Our World,"* included the Beatles debuting the song *"All You Need Is Love"* to an audience estimated at more than 600 million.

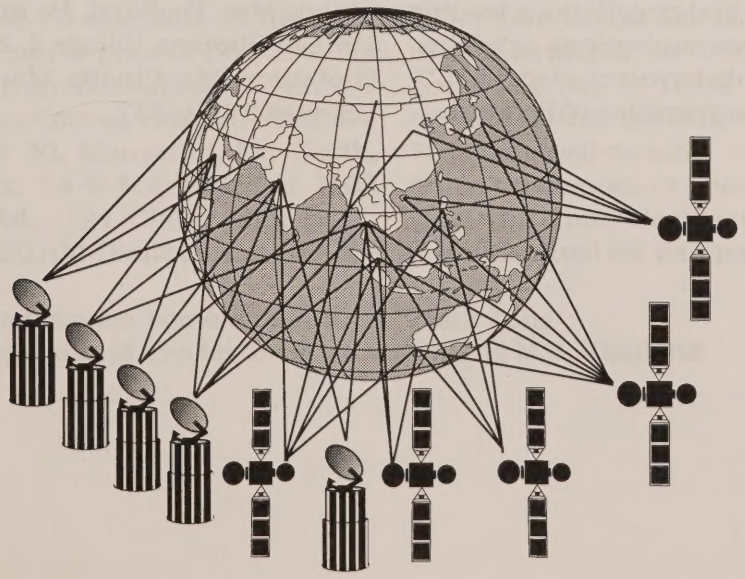
During the course of the telecast, live feeds were interconnected through a pair of early design Intelsats, an American experimental satellite (ATS-1) and a Russian Molniya class bird. About the ground breaking telecast the New York Times would write, *"Our World was a compelling reaffirmation of the potential of the home screen to unify the peoples of the world."*

Less than three decades later, or approximately the period of one generation of mankind, more than 30 million homes in the world are equipped with their own satellite dishes. The early Intelsat, ATS, and Molniya satellites were capable of relaying one (or at most, two) simultaneous TV programmes; each satellite of the current generation easily can deliver as many as 200 programme channels to dish antennas less than 1/30th of the size required for reception of the original *Our World* telecast.

Well before the turn of the century, virtually any location in Asia or the Pacific will have direct access to hundreds of channels of TV, high speed Internet links, and thousands of radio programme channels. It is not an exaggeration to suggest that satellites are redesigning the very fabric of life by creating full-time universal access to 'our world.'

All of this technology creates virtually unlimited opportunities for new business enterprise and personal development. You are holding in your hand a key that will unlock for you, your family, your business the 'secrets' of the 21st century 'Information Revolution.' There has never been a point in the history of the world when so much opportunity has presented itself to mankind. Use what you learn here wisely and your life will forever be changed.

Robert B. Cooper
Mangonui, New Zealand



BIOGRAPHY — MARK LONG

Mark Long is the author of the best-selling **World of Satellite TV**, currently in new eighth editions for Asia & The Middle East; Australia & New Zealand; and Europe, Africa & the Middle East. Mr. Long also is the author or co-author of **The Down To Earth Guide to Satellite TV**, **The Ku-band Satellite Handbook**, and **The Inclined Orbit Satellite Tracking Guidebook** and Founding Publisher of the critically-acclaimed **World Satellite Almanac**—the commercial satellite industry's standard reference on satellite telecommunication systems around the world. In addition to the above-mentioned satellite references, Mark Long is the author of **The World of Home Video Entertainment** and **The World of CB Radio**. More than two million copies of these telecommunications handbooks and technical references have been sold worldwide to date.

The author also has created a series of educational video tapes on satellite TV technologies which are used for corporate training and as part of the curriculum at colleges, universities, and vocational schools around the world.

As a leading expert on global telecommunications technology, Mark Long regularly provides technical consulting services ranging from feasibility studies, observational reports, and satellite event planning, to the implementation of satellite TV networks and negotiations leading to the purchase of communications satellites. Major consulting clients have included the U.S. Naval Academy, the universities of Pennsylvania, Virginia, and Maryland, the U.S. Information Agency, SCOLA, STAR TV, the Billy Graham Evengelical Association, Coopers and Lybrandt, and Comsat Corporation.

Over a ten year period, Mark Long provided the Satellite Broadcasting Communications Association (SBCA) with assistance with its technical training program, frequently lecturing at its annual exhibitions and twice serving as Master of Ceremonies (MC). In 1993 and 1994, he personally organized Asia's first technical conferences on home satellite TV technology—which were held in Phuket and Chiang Mai, Thailand, respectively.

Mark Long is a graduate of the School of Communications at the University of Central Florida. During the late 1970s, he served as transmitter manager for radio station WUTZ-FM in central Tennessee and telecommunications consultant for the United Nations (UN) Non Governmental Organizations (NGO) "Plenty" and the "Pacific Foundation." During the early 1980s he also was the telecommunications advisor and shipboard radio operator for the international "Greenpeace" environmental organization.

An amateur radio enthusiast (WA4LXC), Mr. Long also has been a member of the American Institute of Aeronautics and Astronautics (AIAA) and the International Society of Satellite Professionals (ISSP). Mr. Long currently resides in Chiang Mai, Thailand. He may be contacted at 199/43 Chotana Village 2, Soi 7, Changpuak, Photaram Rd., Chiang Mai 50300 Thailand. Tel: 66-53-211-337.

Introduction

The *Satellite TVRO Handbook* consists of various educational materials expressly written for the international direct-to-home satellite TV industry which the author had extensively researched during the past twelve years. Although this publication is a stand-alone reference to the basic technologies of satellite TV reception, it also serves as the official technician certification course textbook for the **SPACE—Pacific** satellite trade association serving members in Australia, New Zealand, Papua New Guinea, the islands of the South Pacific and beyond.

The complete **SPACE—Pacific** *Satellite TV Technology Correspondence Course* includes this textbook, a one-hour companion videotape entitled *Satellite TV Technology Overview,* more than 40 pages of supplementary classroom materials, exams, correspondence with the course teacher and a course completion certificate. Each original purchaser of *The Satellite TVRO Handbook* receives a nontransferable coupon valid for six months which entitles the purchaser to a US$ 75 discount off the complete certification course price of US$ 394. For further information on the *Satellite TV Technology Correspondence Course,* contact: **SPACE—Pacific,** P. O. Box 30, Mangonui, Far North, New Zealand. Fax: 64-9-406-1083; or **MLE (Thailand) Co. Ltd.**, 124 Chang-klan Road, #110, Chiang Mai 50100 Thailand. Fax: 66-53-818-435.

Some readers may notice some similarities between certain segments of this textbook with the first three editions of the *World Satellite Almanac* (1985, 1987, & 1991) which were written and compiled by this author. In 1994, I sold all rights to the *World Satellite Almanac* to American satellite publisher Phillips Business Information (PBI) which has since published two more editions of the Almanac for 1995 and 1996. It was PBI's decision, however, to restrict the contents of the PBI versions of the *World Satellite Almanac* primarily to satellite footprint maps, other technical specifications for all the world's communications satellites and directory style listings for major satellite industry companies, service providers and governmental or non-governmental satellite organizations.

As Phillips Business Information had no further plans to use the many tutorial chapters covering various aspects of satellite TV technologies which I had included in my first three editions of the Almanac, PBI graciously has given permission for the author to include the latest revised versions of these educational materials within the confines of this textbook. I therefore would like to thank Phillips Business Information for their written permission governing use of these certain materials in order to further the educational goals of SPACE Pacific as well as other satellite trade associations, businesses or vocational schools worldwide which may elect to use this publication as a training tool for its members or students.

Mark Long
Chiang Mai, Thailand

Chapter 1

An Introduction to Satellite Technology

The "global village" envisioned by Marshall McLuhan is now a reality. Today's worldwide satellite network can almost instantaneously transmit live news and entertainment to hundreds of millions—or even billions—of people.

Powerful tools for shaping the future, satellites have forever altered the common perception of the world we held just thirty short years ago. Events such as the *Live Aid for Africa* concert, the *Olympic Games*, and the war in the Persian Gulf should be regarded as watershed events that showed how satellites can help establish ad-hoc communication networks.

The Rings of Earth

Our planet is encircled by a ring of man-made communications satellites that generate an invisible electromagnetic web. This web bonds our world together with a continuous exchange of video, audio, and data information.

These satellites inhabit a narrow band of outer space 22,753.2 miles above the Earth's equator and complete one revolution of their orbits every twenty-four hours. Because they take the same amount of time the Earth takes to complete a single rotation on its axis, satellites appear to maintain fixed positions in the sky relative to the Earth's surface. This is why these orbiting electronic message processors are referred to as *geostationary* satellites.

International Satellite Systems

In 1962, President John F. Kennedy signed an Act of Congress which gave birth to the International Telecommunications Satellite Organization (INTELSAT)—the world's most successful international cooperative. In 1965, the International Telecommunications Satellite

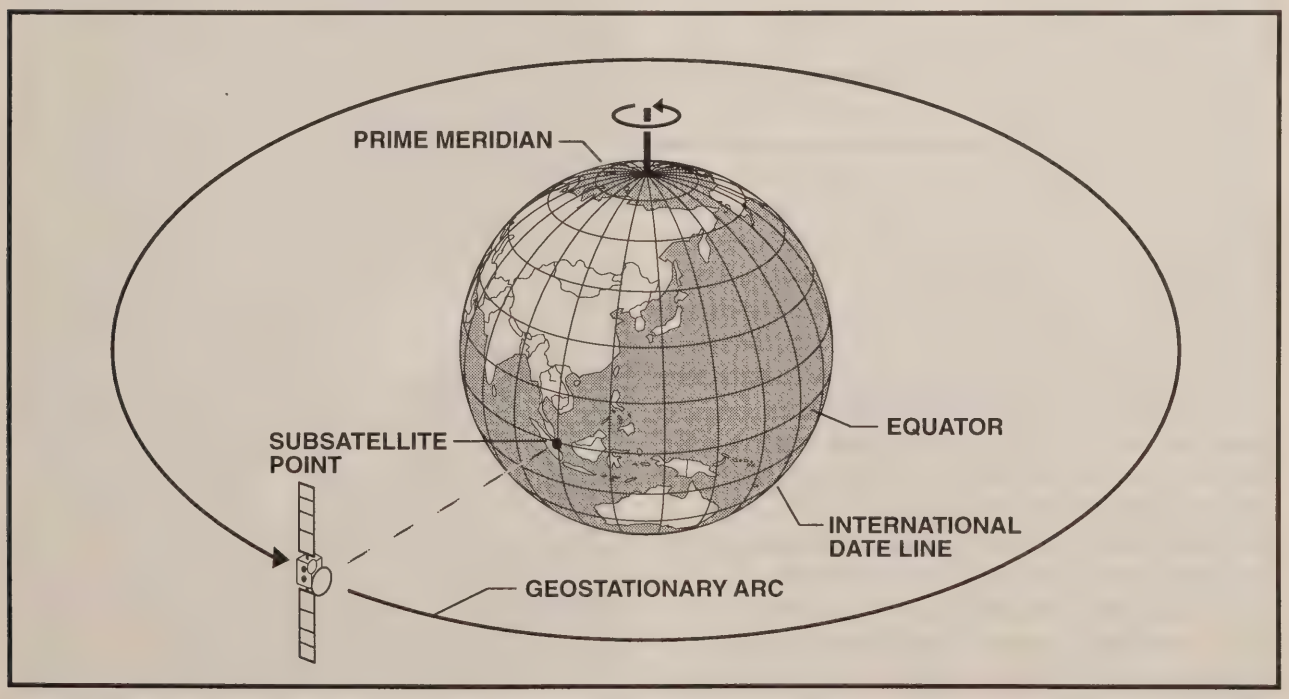


Fig. 1-1. The Geostationary Satellite Orbit.

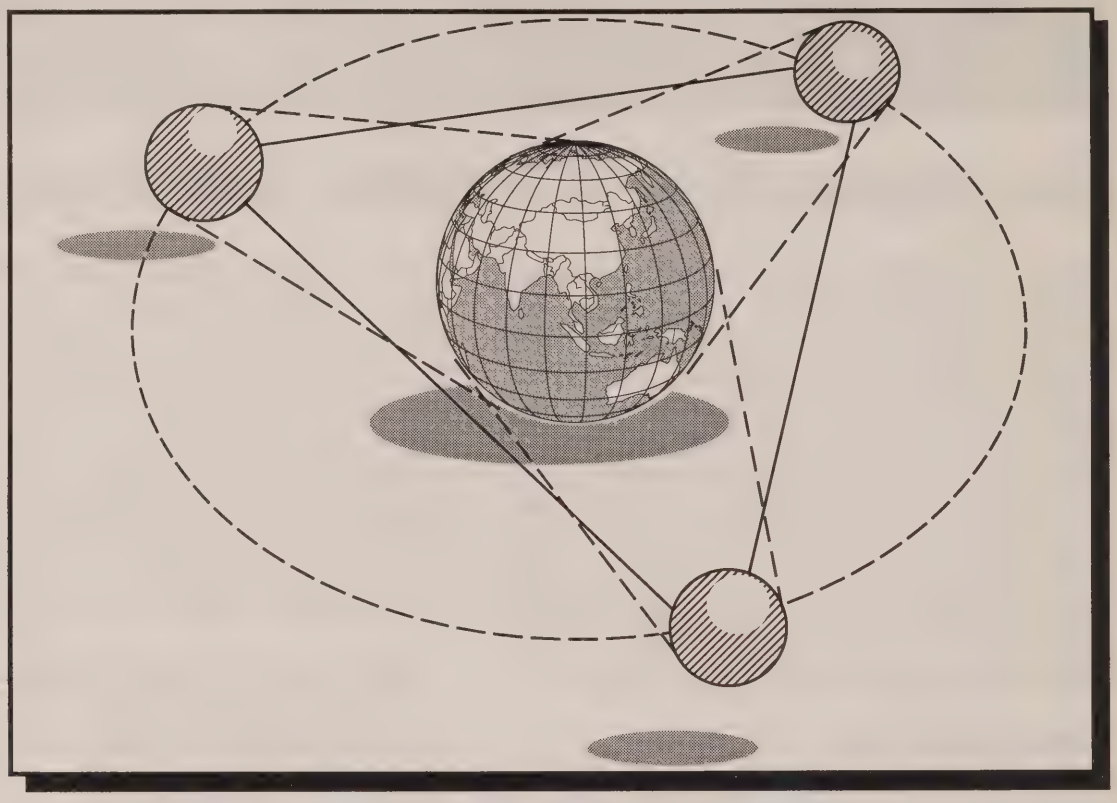


Fig. 1-2. It was Arthur C. Clarke who first envisioned the creation of a global satellite system back in 1945.

Organization (INTELSAT) launched INTELSAT I—also known as Early Bird—into orbit over the Atlantic Ocean. INTELSAT I provided the first continuous transatlantic satellite link, but it was a far cry from today's complex communications spacecraft. INTELSAT I could either transmit 240 voice circuits or a single television signal. This primitive geostationary satellite carried an omnidirectional antenna that radiated signals outward from the satellite in a full 360 degree arc. This meant most of the transmitted signal radiated uselessly into space. The small portion of energy that finally did reach the Earth was "squinted," or concentrated over the Northern Hemisphere to interconnect telecommunications systems in Western Europe and North America. To keep the antennas oriented for transmitting signals earthward, the cylindrical body of INTELSAT I spun about its axis at a fixed rate. Numerous other satellites later used this spin stabilization technique.

In 1966 and 1967, INTELSAT placed a second generation of spin-stabilized telecommunications spacecraft into geostationary orbits. These INTELSAT II satellites also used omnidirec-

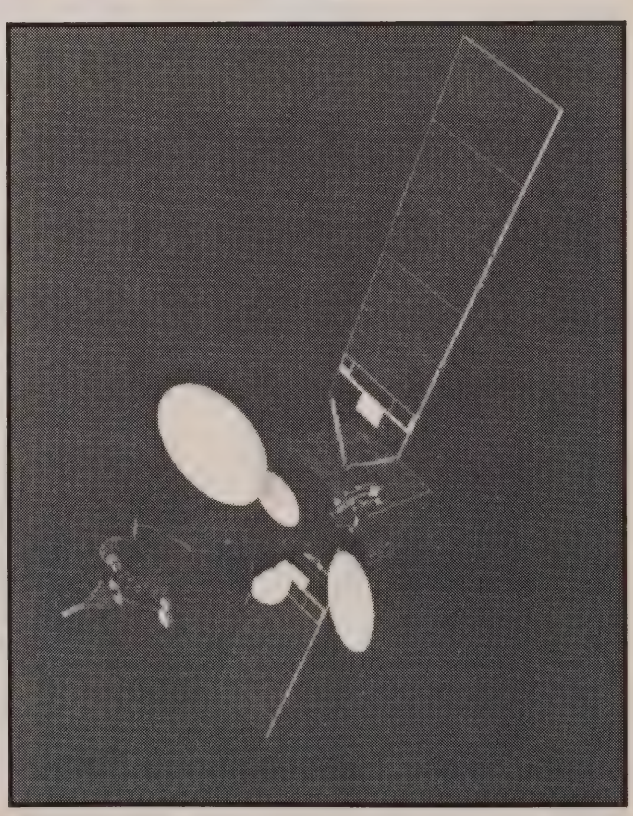


Fig.1-3. An INTELSAT V satellite. (Courtesy INTELSAT.)

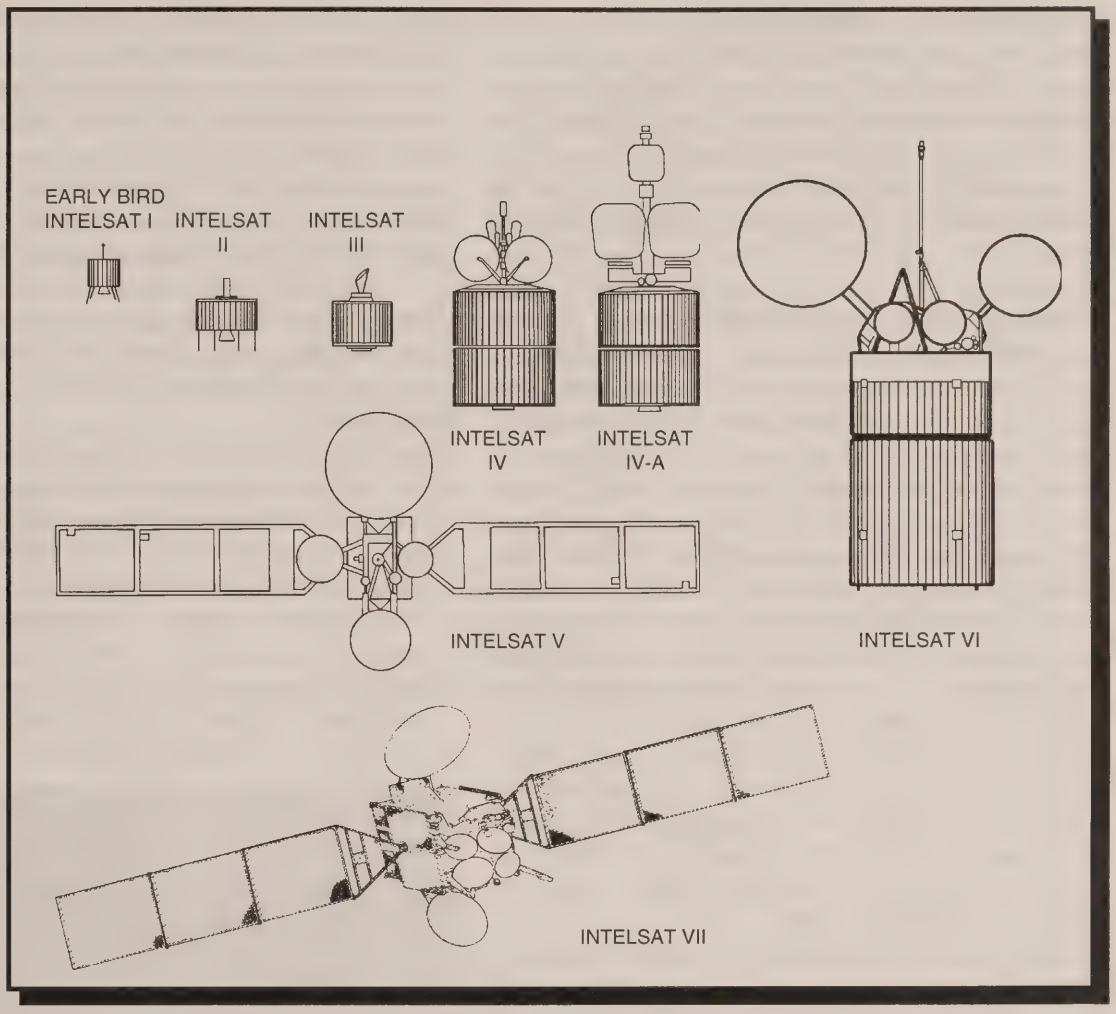


Fig. 1-4. The evolution of operational INTELSAT spacecraft design from 1965 to the present.

tional antennas, but each satellite concentrated its energy into a *global beam.* These beams can reach any earth station within the more than forty percent of the Earth visible from the satellite's orbital position. The development of the global beam permitted INTELSAT to extend telecommunications services to locations South of the equator.

By 1969, INTELSAT had deployed three spin-stabilized INTELSAT III satellites to orbital assignments over the Atlantic, Pacific, and Indian Ocean Regions. This fulfilled Arthur C. Clarke's original vision of a globe-girdling satellite system that could access just about any spot on Earth. INTELSAT III satellites could carry up to 1,500 simultaneous voice circuits and one TV signal, a dramatic increase in capacity. For the first time, INTELSAT satellites also carried antennas that were directed toward the Earth at all times. To accomplish this, the platform supporting the satellite's antenna spun at precisely the same speed as the satellite's outer body, but in the opposite direction.

To meet increased demand, INTELSAT began deploying INTELSAT IV-series satellites in the 1970s. Each INTELSAT IV spacecraft carried twelve transponders that collectively could relay an average of 3,750 simultaneous telephone circuits and two TV channels. INTELSAT IV satellites not could only broadcast using global beams, but also carried two *spot beam* antennas. These spot beams were designed to

be steerable so that INTELSAT could point them to concentrate signals over designated areas of the Earth's surface. Giant antennas 100 or more feet in diameter had to be used to receive the early INTELSAT satellite transmissions, limiting reception of satellite signals to just a handful of government-owned earth stations.

Regional Satellite Systems

In 1977, the European Conference of Postal and Telecommunications Administrations (CEPT) founded the European Telecommunications Satellite Organization (Eutelsat), an international cooperative charged with the responsibility of owning and operating a Pan-European satellite network. In 1978, the European Space Agency began operating an Orbital Test Satellite (OTS-2) to investigate the feasibility of using satellites operating on super high frequencies to serve the telecommunications needs of Europe. The success of the OTS-2 program led to the launch of the first Eutelsat satellite on June 26, 1983. As of August 15, 1994, there were seven Eutelsat communications satellites serving locations in Western and Eastern Europe, Northern Africa, and portions of the Middle East.

Other regional satellite systems also are playing major roles in various areas of the world. These include the Moscow-based Intersputnik system; the Arabsat cooperate venture of the League of Arab States; and the AsiaSat, Apstar, Palapa, PanAmSat, Astra, Columbia, and Orion satellite systems.

Domestic Satellite Systems

In 1966, the former Soviet Union became the first country in the world to operate a domestic satellite network. The first Molniya (Russian for "Lightning") satellites sent TV and radio broadcasts from Moscow to remote areas throughout Eurasia. Instead of using the geostationary arc, the Soviets decided to space four Molniya satellites at equal intervals along the path of a highly elliptical orbit. As one satellite left view, the next in line entered the active portion of the elliptical orbit. Each satellite could provide up to six hours of coverage of the Soviet Union before it passed beyond the tracking range of the Russian earth stations. The Russians have since gone on to deploy several geostationary satellite systems, including Ekran, Express, Gals, Gorizont and Raduga.

In the early 1970s, Canada and the United States began satellite network programs of their own. The first Canadian Anik (Eskimo for "little brother") and U.S. Westar domestic satellites carried a dozen transponders, quite an improvement over the more limited channel capacity of the early INTELSAT and Molniya spacecraft.

By 1975, RCA had developed its own Satcom series of communications spacecraft. These North American domestic communications satellites, or *domsats*, pioneered the use of *dual linear polarization*. This meant that twenty-four transponders—twelve of each polarity—could fit into the limited frequency bandwidth assigned for commercial satellite transmissions.

In Europe, a joint satellite venture between France and Germany deployed experimental

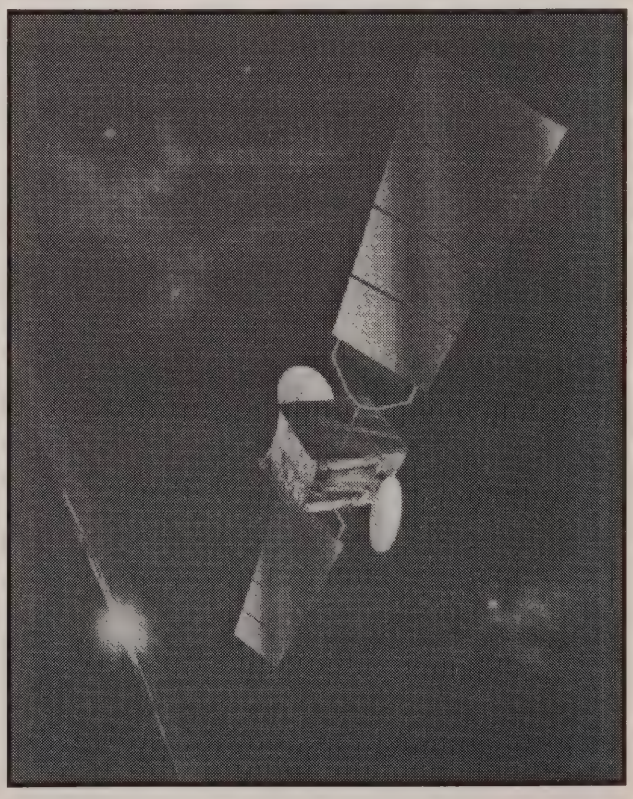


Fig. 1-5. The AsiaSat 2 satellite. (Courtesy Asia Satellite Telecommunications Co., Ltd.)

Symphonie satellites in 1974 and 1975. The Symphonie engineers were the first to design a geosynchronous satellite that used a *three-axis stabilization* scheme. Internal gyros that sensed changes in three axes of the satellite's position could bring the spacecraft back to the proper orientation by firing thruster jets. This three-axis stabilization scheme is now used by many of the world's satellite manufacturers.

Symphonie I and II were used during their operational lifetimes by many countries and organizations, including France, Germany, India, Iran, The Ivory Coast, and the United Nations. Many features first used on the Symphonie satellites were later included into the design of today's INTELSAT V, VI and VII series spacecraft.

The Dawn of DBS

On September 30, 1975, Home Box Office used satellites to transmit the "Thriller in Manila"—the world heavyweight championship boxing match between Joe Frazier and Muhammad Ali—to cable TV systems in Jackson, Mississippi, and Fort Pierce, Florida. In the ensuing months, HBO began providing regular program feeds to cable TV affiliates at locations around the country. HBO's pioneering efforts led directly to the introduction of other cable TV services, first in the United States, and then at other locations around the world. Suddenly whole communities could plug into TV programs from around the world.

On January 17, 1976, the experimental Communications Test Satellite (CTS) was launched from Cape Canaveral, Florida. A joint American/Canadian effort, CTS was the first spacecraft to carry a 200 watt power amplifier. The Hermes direct broadcast satellite project first demonstrated the practicality of beaming satellite TV programs directly to households equipped with tiny receiving "dishes."

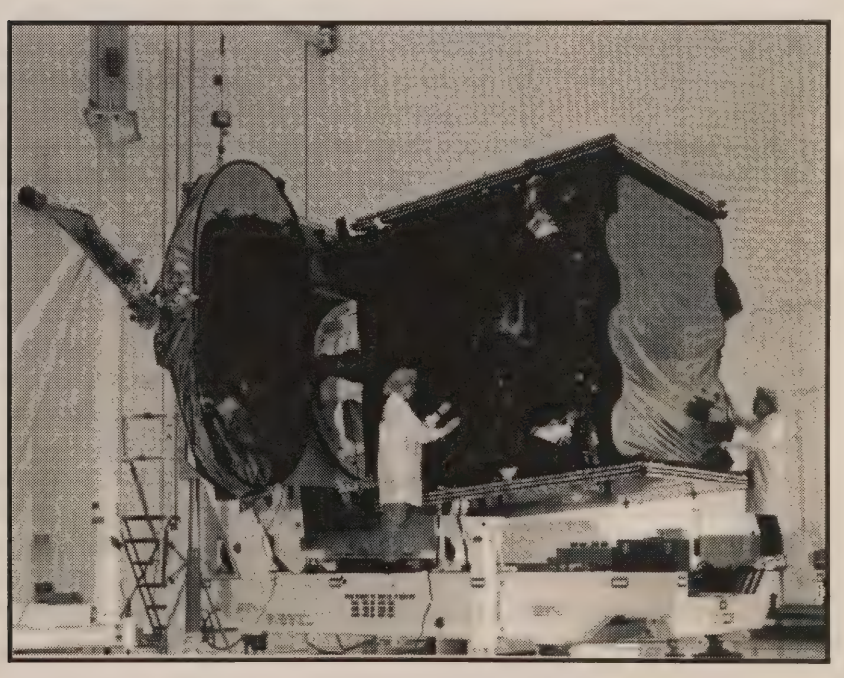


Fig. 1-6. A pre-launch view of the Optus B3 domestic communications satellite. (Courtesy Hughes Aircraft Co.)

Basic Satellite Space Segment Terminology

Satellite Launches

Orbital Location:	The assigned orbital position of the spacecraft over the Equator in degrees of longitude.
Launch Date:	The date of launch for existing satellites or the expected launch date for upcoming geostationary spacecraft.
Launch Vehicle:	Identifies the vehicle that placed or will place the satellite into geostationary orbit.
Mission Life:	An estimate of the number of years the satellite will be operational.

Spacecraft

Satellite Type:	Satellite manufacturer(s), model number, and stabilization type.
Weight:	Mass of the satellite in orbit.
Dimensions:	English and metric measurements of the satellite.
Electric Power:	The amount of power in watts generated by the solar voltaic array on board the satellite, usually expressed as an end of life (EOL) value.

Satellite Communications Payload

Uplink/Downlink:	The frequency band(s) in Gigahertz (GHz)
Frequencies:	(1 Gigahertz = one billion cycles per second) used by the satellite to receive and retransmit signals.
Channels:	The total number of transponders carried by the satellite.
Bandwidth:	Total transponder bandwidth in Megahertz (MHz) (1 Megahertz = one million cycles per second) available for carriage of telecommunications traffic.
Channel Polarity:	The sense of polarization(s) employed by the satellite.
Power (EIRP):	The nominal effective isotropic radiated power (EIRP) of the satellite signal in decibels referenced to 1 watt of power (dBW).
Beam Coverage:	Primary region(s) or area(s) reached by the satellite's transmissions. In many instances, a particular satellite transponder may be switched between more than one antenna coverage pattern.
Power (watts):	The amount of output power in watts produced by the satellite's traveling wave tube amplifiers (TWTAs) and/or solid state power amplifiers (SSPAs).
Capacity:	The maximum amount of telecommunications traffic that the satellite could carry at any given time.
Telemetry beacon:	The frequency in GHz at which the satellite automatically transmits information on the status of its operations.
Command:	The frequency in GHz at which the master ground station sends control signals to the satellite.
Transponder No. :	The numeric code assigned by the satellite manufacturer to each transponder. For some C-band satellites, a second number is presented in brackets which corresponds to the 24 channel format used by most American C-band satellites.
Frequencies:	Provides the uplink and downlink center frequency in MHz or GHz for each transponder carried by the satellite.

Satellite Footprints

Geostationary telecommunications satellites beam their microwave signals in a straight path to the Earth. The satellites focus these microwave signals onto specified portions of the Earth's surface to most effectively use the limited power of their transponders. These focussed signals create unique *beam patterns,* also called "footprints."

Domestic satellites broadcast standard beam patterns that usually are centered on the country broadcasting the services. By contrast, international satellites are designed to perform multiple roles, so they often transmit a number of different beam patterns with distinctive shapes and power concentrations. In addition, beam patterns transmitted by international satellites may center on regions far removed from the country originating the signal.

The strongest portion of any beam pattern normally is the beam center, also called the *boresight.* As the geographic distance from beam center increases, signal levels usually drop off gradually. It is essential to know a specific satellite's signal strength at a given location in order to plan any earth station installation.

Satellite coverage maps reflect the performance level satellite engineers expect for a satellite in a particular orbital location. In many cases, these coverage maps were derived from computerized studies of satellite antenna performance tests conducted at ground level before the actual launch of the satellite. However, as we all know, real life does not always precisely follow even the best-laid plans of engineers. Sometimes, signal levels for a location may be somewhat higher or lower than those suggested by the data in this book. Whenever possible, readers who intend to install an earth station should contact informed sources near the planned site for confirmation of signal strengths.

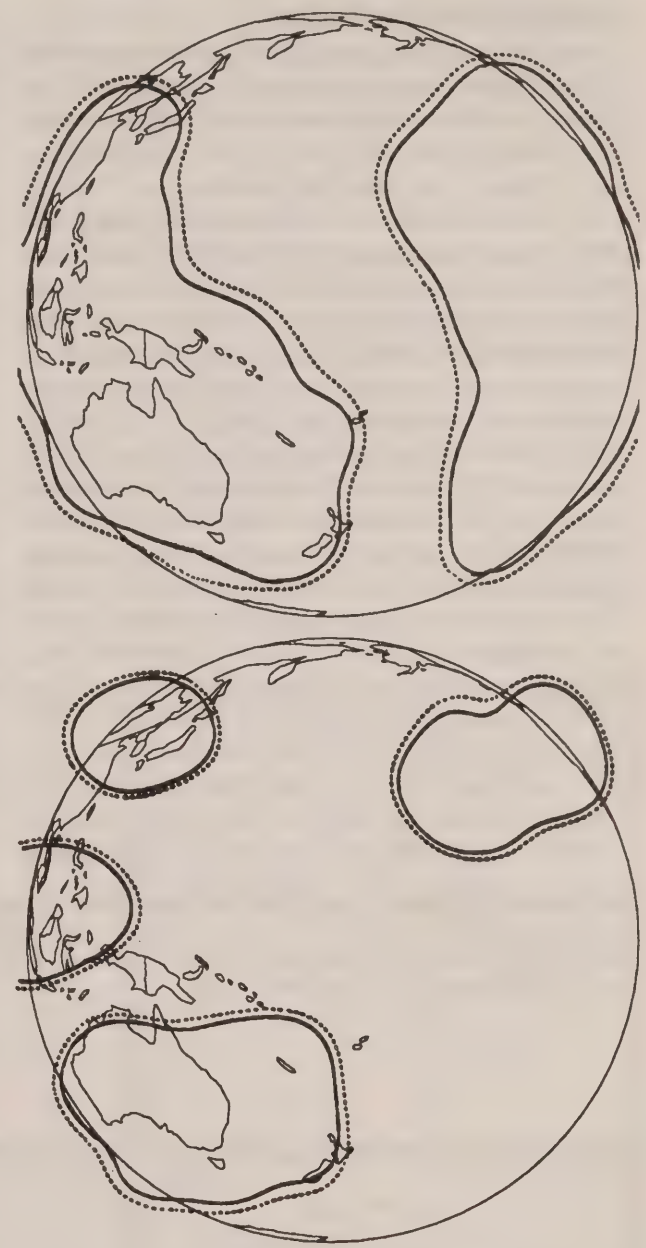


Fig. 1-7. INTELSAT VIII C-band hemispheric and zone coverage beams from 174 degrees east longitude.

Interpreting Satellite Footprint Maps

Contour lines on a satellite coverage or "footprint" map indicate signal strength values at various locations. The further a location is from beam center, the lower the signal level indicated by the contour line. These contour lines extend out to the beam edge of the signal—the limit of its effective visibility. The contour at the beam edge normally shows the lowest signal strength of any contour.

A contour line indicates a satellite signal level as the effective isotropic radiated power (EIRP) arriving at that location. Values are expressed in dBW, or deciBels referenced to one watt of power.

Global Beam Footprints

A satellite *global beam* antenna transmits a footprint that stretches over 42.4 percent of the Earth's surface, the maximum area a single geostationary satellite can "see." Although a global beam provides the maximum coverage area, it also has the lowest signal levels of any pattern because the satellite spreads its limited amount of signal power over such a vast area. Global beam signals also have low levels when certain satellites use global horn antennas with relatively small apertures. For example, a global antenna carried by an INTELSAT V spacecraft exhibits signal gain of no more than 15 dBi (gain in dB referenced to an isotropic reference antenna). By contrast, the same satellite's hemispheric and zone beam transmitting antennas produce more than 20 dBi of gain.

The measurement of gain (dBi) is made using an imaginary transmit antenna conceived as a reference by engineers. Called a standard isotropic antenna, this antenna theoretically transmits signals equally in all directions at once and has a gain of 0 dB. However, the shape of a real satellite antenna is such that signals transmit within a narrow corridor centered out to the front of its reflective surface. Transmitting through this corridor enables the satellite to send signals in the desired direction, which provides a much higher level than if the signal was equally dispersed in all directions at once.

The beam center EIRP level for a given satellite transponder can be determined by adding the gain (in dBi) of the satellite's transmitting antenna to the power level (in dBW) produced by each traveling wave tube amplifier (TWTA) or solid state power amplifier (SSPA) on board the spacecraft. Then subtract any loss caused by the satellite's multiplexer and waveguide, which connect the amplifier to the antenna.

Global beam transponders are essential components of INTELSAT, Intersputnik, and Inmarsat satellites, which typically transmit transoceanic TV, telephony, radio, and data. Global beam transponders regularly provide the world's major TV networks with a daily flow of TV news and sports programming.

Hemispheric Beam Footprints

Satellites not broadcasting transoceanic communications normally use antennas that radiate signals within a smaller coverage area.

Fig. 1-8. INTELSAT VII Hemispheric & Zone (bottom left) and Ku-band Spot Beam (bottom right) Coverage Zones from 177 degrees east longitude.

INTELSAT spacecraft, for example, use hemispheric beam antennas to cover approximately twenty percent of the Earth's surface to the East or West of their orbital positions. Russian Gorizont and Raduga satellites use a Northern hemispheric beam that concentrates signals onto the Northern half of the globe. Because hemispheric beam antennas restrict coverage to only twenty percent of the Earth's surface, signal levels are at least 3 dB higher than those for global beam antennas fed with the same amount of power.

Zone and Spot Beam Footprints

Satellite system operators sometimes want to concentrate satellite signals within areas much smaller than would be covered using global and hemispheric beams. These zone or spot beams concentrate signals into tight patterns that cover less than 10 percent of the Earth's surface. Zone and spot beams are carried by all INTELSAT and Russian Gorizont spacecraft. Most regional and domestic satellites are designed to provide spot beam coverage.

Signal Spill Over

The satellite footprint maps provided by the satellite operators show that satellites theoretically deliver little in the way of usable signal levels outside the intended coverage area of the spacecraft. Of course, these satellite footprint maps do not always indicate the true signal levels to be found at the edge of a specific satellite transmit coverage area. TVRO owners in Central and South America, for example, have found that the actual beam-edge EIRP signal levels from some of the North American C-band satellites greatly differ from the theo-

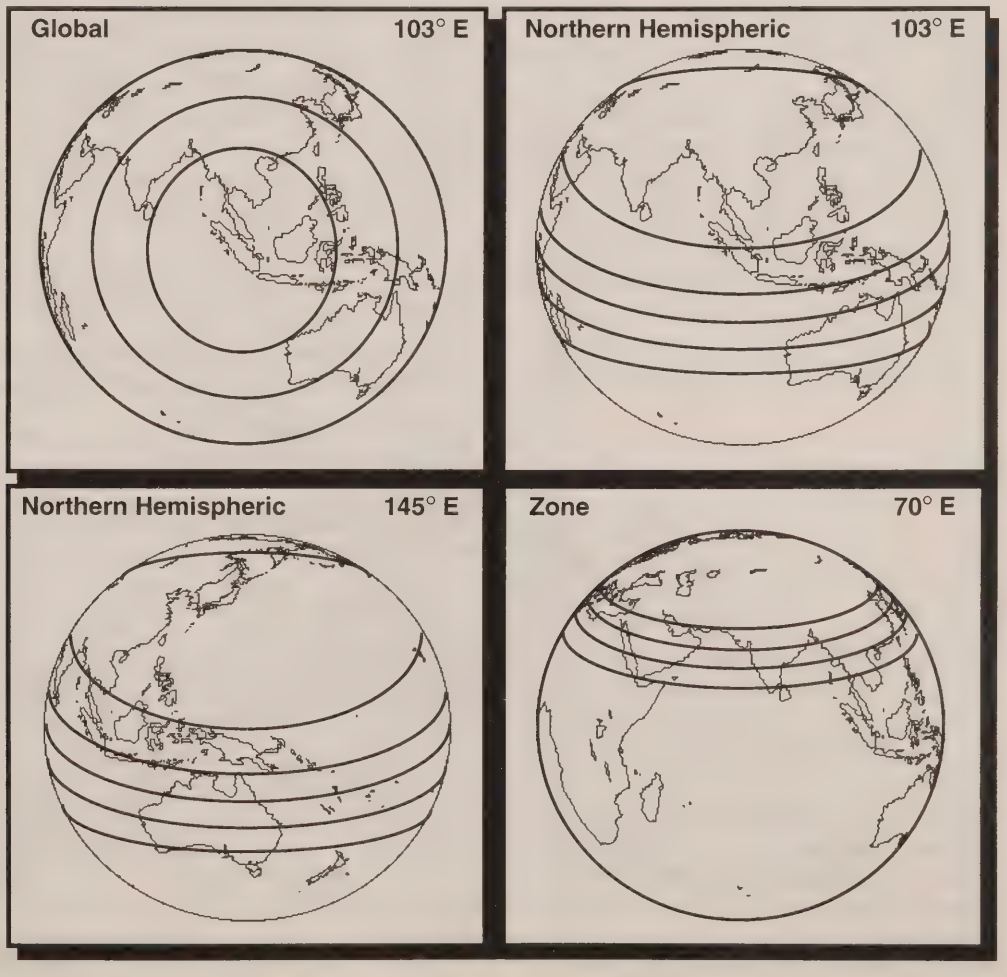


Fig. 1-9. Russian STATSIONAR Global, Northern Hemispheric and Zone Beam Coverage.

retical presentations of these footprints. In some cases, satellite earth station enthusiasts in Latin America have discovered usable signals hundreds of miles further South than indicated on the coverage maps. This phenomenon is called "signal spillover."

TVRO operators in Central and Southern Africa also have discovered Ku-band signals from the European Astra satellites at locations far distant from the coverage areas anticipated by the satellite designers. Before purchasing equipment, would-be earth station operators who live outside the primary coverage areas of the satellite should obtain satellite performance indications, either by conducting a preliminary site survey or by asking other earth station operators within the area.

All satellite footprint maps show the signal strength required from uplinks at different locations, to fully saturate the satellite transponder. FM TV transponders are normally run at saturation, as this gives the highest EIRP. Most satellites have their transponder gains adjustable by ground command, so saturation can be achieved for a range of PFD values, allowing the satellite operator a degree of tradeoff between C/NR and saturation. But if the uplink signal is allowed to fall below the saturation value, downlink power also will start to fall, and with the low margins of a DBS service this will immediately result in "sparklies" in the picture, even though the uplink C/NR is unchanged.

The World Satellite Almanac, now published by Phillips Business Information, Inc., contains an up-to-date global presentation of communication. satellite footprint maps and other pertinent technical specifications. For further information, contact Phillips Business Information, Inc., 1201 Seven Locks Road, Suite 300, Potomac, Maryland 20854.

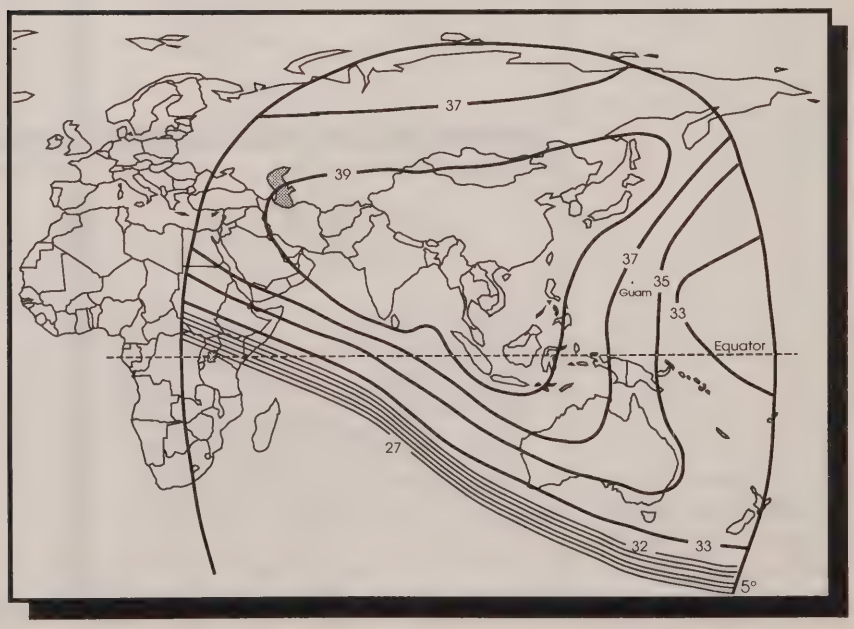


Fig. 1-10 . AsiaSat 2 C-band Coverage Beam. (Courtesy Asia Satellite Telecommunications, Ltd.)

Chapter 2

Exploring the Satellite System

All telecommunications satellites are made up of a number of subsystems—each with its own unique role to play within the overall design of the spacecraft. Subsystems not only independently perform assigned tasks, but also interact with one another to achieve the satellite's long-term mission objectives.

The Propulsion Subsystem

Most satellites have catalytic and/or electrothermal propulsion systems that provide the required thrusting power for orienting and maintaining the position of the spacecraft. Hydrazine thrusters provide the impulses necessary for stationkeeping purposes. Most satellites also are equipped with a payload assist module (PAM) and an apogee or perigee kick motor (AKM or PKM). The PAM provides the thrusting power required for maneuvering the satellite away from the launch vehicle and into the initial geostationary transfer orbit (GTO). An AKM or PKM is used to maneuver the satellite from the apogee or perigee point of the transfer orbit to the satellite's final orbital assignment.

No geostationary satellite can remain on station without taking further measures to stabilize its position. The gravitational effects of the Sun and Moon exert an influence that will cause any spacecraft's orbit to shift over time. Streams of particles generated by solar flares on the Sun's surface can push the satellite out of its orbit. If the latitudinal position of the satellite changes substantially, the spacecraft will begin to meander in an inclined "figure-eight" orbit centered over the Earth's equator. All associated ground stations must track movements within this figure-eight orbit to maintain continuous contact with the spacecraft. Satellite tracking is not economical for networks which have a large number of receiving earth stations.

Most domestic satellites are required to maintain their orbital assignments to within ± 40 km or ± 0.1 degree of longitude. This tiny amount of orbital drift can only be detected by earth stations using extremely large antennas. For all other ground stations, a ± 0.1 degree drift is negligible.

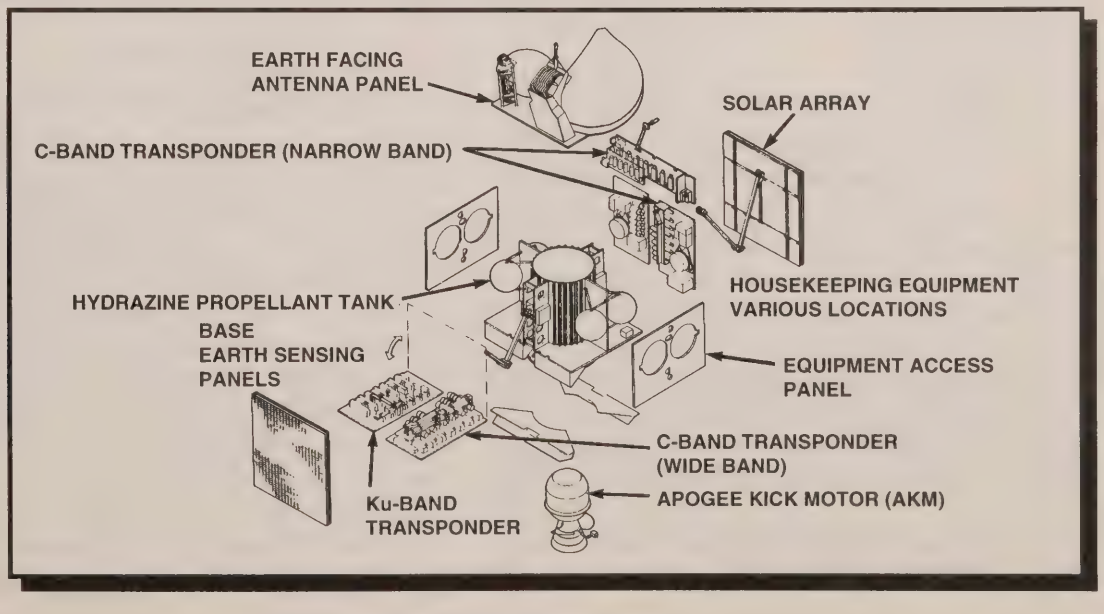


Fig.2-1. Satellite subsystems for the Chinasat 5 Satellite (Courtesy of GTE SPACENET.)

Ground-based engineers regularly send command signals to the spacecraft to fire stationkeeping thrusters in pairs. This countermeasure corrects for any North/South or East/West drift in orbital position. Any major movement of the satellite to the East or West would maneuver the spacecraft away from its assigned position over the Earth's equator. If no correction of orbital drift to the North or South was supplied, the inclination of the satellite would slowly increase over time, attaining a level of three or more degrees over the course of a one-year period.

Spacecraft Control Subsystem

Each *spin-stabilized* satellite maintains a proper orientation by spinning the spacecraft's cylindrical body at a fixed rate about its axis. To maintain the correct position of the spacecraft's antenna payload, a motor is used to spin the antenna platform at precisely the same speed as the satellite's outer body, but in the opposite direction.

Three-axis stabilized satellites employ a combination of fixed momentum wheels and Earth-sensing, infra-red sensors that can detect changes in the relative position of the spacecraft's pitch, roll, and yaw axes. Pitch control normally is maintained by momentum bias. Control of roll and yaw is provided by tiny jet thrusters that automatically fire in bursts to bring the spacecraft back to the desired orientation or *attitude*. The control subsystem also drives the solar array for three-axis stabilized systems. A clock-driven tracking mechanism rotates the arrays at approximately 15 degrees per hour. This mechanism continuously orients the energy producing solar cells Sunward throughout each 24-hour orbital period.

Electrical Power Subsystem

All commercial communications satellites have solar arrays which convert Sunlight into electricity. These photovoltaic arrays are the primary source of power for the satellite. The arrays also charge the satellite's battery system so that power will be available during solar eclipses or whenever the instantaneous power requirements of the spacecraft are exceeded.

Most of the central body surface of spin-stabilized satellites are covered with solar cells. The regular spin rate of the spacecraft's main body causes these cells to be illuminated almost continuously by Sunlight. Spin-stabilized satellites such as the INTELSAT VI spacecraft are capable of generating up to 2,600 watts of power at the beginning of their operational lifetimes.

Three-axis stabilized satellites have wings covered with photovoltaic solar cells. Each

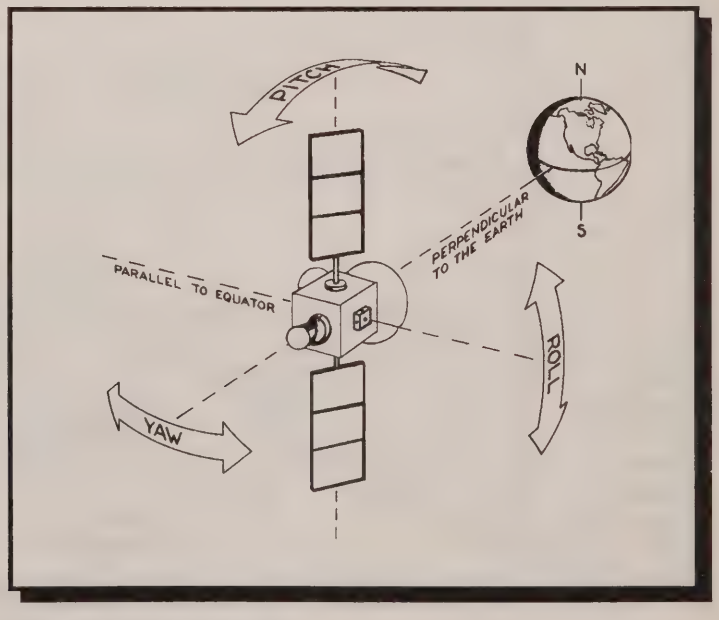
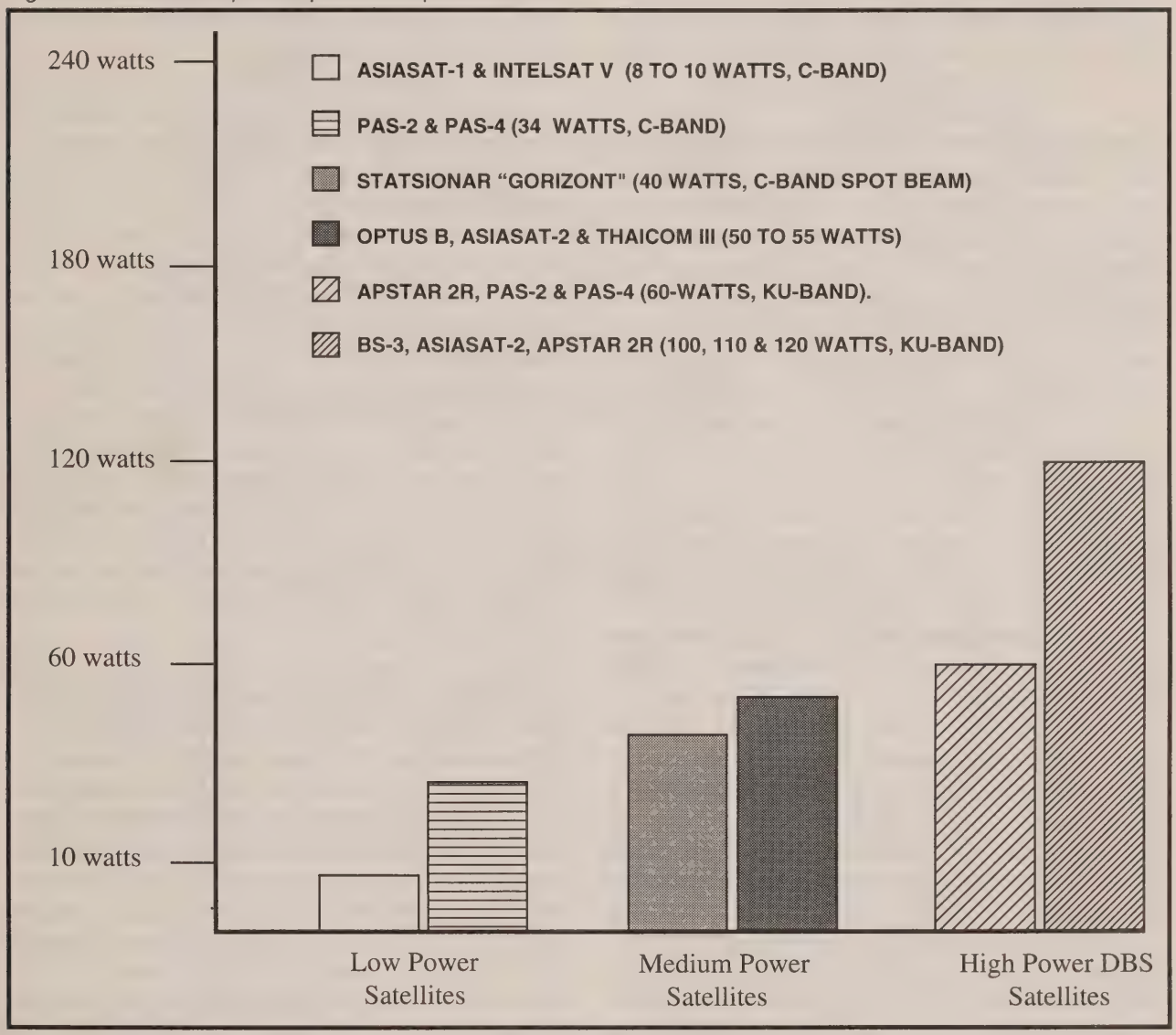


Fig.2-2. Three-axis stabilization.

Fig.2-3. Satellite transponder power comparison chart.


240 watts
180 watts
120 watts
60 watts
10 watts
ASIASAT-1 & INTELSAT V (8 TO 10 WATTS, C-BAND)
PAS-2 & PAS-4 (34 WATTS, C-BAND)
STATSIONAR "GORIZONT" (40 WATTS, C-BAND SPOT BEAM)
OPTUS B, ASIASAT-2 & THAICOM III (50 TO 55 WATTS)
APSTAR 2R, PAS-2 & PAS-4 (60-WATTS, KU-BAND).
BS-3, ASIASAT-2, APSTAR 2R (100, 110 & 120 WATTS, KU-BAND)
Low Power Satellites
Medium Power Satellites
High Power DBS Satellites

INTELSAT V satellite, for example, has 17,568 solar cells that together can produce 1,742 watts of power at the beginning of the spacecraft's mission lifetime.

Large photovoltaic arrays are used whenever the overall power demands for a particular satellite are quite high. The wing span of these arrays can range from 40 to 80 feet. For example, the wing span of each INTELSAT V satellite is 51 feet from wing tip to wing tip. Direct broadcast satellites such as the Hughes DirecTv DBS-1 and DBS-2 spacecraft use even larger arrays to produce more than 4,000 watts of power.

Tracking,Telemetry, and Command (TT&C) Subsystem

Every satellite must be able to receive command signals from controlling engineers down on the ground. Command signals can be used to reposition the spacecraft, unfurl the satellite's antennas and solar arrays following the initial deployment to geostationary orbit, connect one or more transponders to a specific antenna beam, or switch to a redundant receiver, transmitter, or amplifier in the event of a component failure.

Telecommunications satellites also carry auxiliary transmitters and antennas that transmit

telemetry beacons. These beacons provide the controlling engineers with a tracking signal and a continuous stream of real-time data on the internal functioning of the spacecraft.

Electronic Communications Subsystem

All communications satellites carry at least one or more *transponders*—a combination of an uplink receiver and downlink transmitter which acts as a repeater of a single telecommunications channel. The satellite's receiving antenna and feedhorn array captures signals that have been transmitted by one or more uplink earth stations. Once captured, the signals pass through a switching network that is linked to an uplink receiver.

The uplink receiver downconverts the incoming signals to a block of intermediate frequencies (IF) that contain the same information provided by the original telecommunications signal. This IF signal passes through a switching matrix that assigns the communications traffic to a particular downlink channel group.

The Intermediate Frequency (IF) signals are then upconverted to the appropriate downlink frequencies and routed to an amplifier. The output signal level generated by the amplifier may range from 5 to 240 watts of power, depending on the role of the particular satellite.

Satellite manufacturers use two different types of microwave amplifiers: traveling-wave-tube-amplifiers (TWTAs) and solid-state-power-amplifiers (SSPAs). A TWTA is a special type of vacuum tube with a heated cathode and a high-voltage power supply. This type of amplifier has two distinct disadvantages. Vacuum tubes can become "soft" after a long period of operation; this can result in a noticeable degradation of the output power level. Whenever multiple telecommunications signals occupy the same transponder, operating engineers must back-off the power level of each individual signal by 3 or more dB to prevent the generation of intermodulation distortion products.

Each solid-state-power-amplifier (SSPA) contains multiple Gallium-Arsenide Field-Effect Transistors. SSPAs generate low levels of intermodulation distortion products whenever multiple carriers occupy a given transponder. The main disadvantage of SSPAs is that they produce lower power levels than what TWTAs are capable of generating.

The output of each amplifier is connected to an output multiplexer which recombines the outgoing signals and routes them through a waveguide that terminates at the transmitting antenna's feedhorn array. This feedhorn array creates a unique transmission pattern through the in-phase combination of distinct multiple feed elements. The parabolic curvature of the transmit antenna focusses the outgoing microwaves into a narrow beam of energy that is directed toward the intended coverage area.

At present, it is impossible to physically repair a satellite once it has been placed into geostationary orbit. Redundant receivers, transmitters, and amplifiers are designed into the electronic communications subsystem to provide the controlling engineers with the means to bypass individual components in the event that one or more fails.

Communications Frequency Assignments

Like all other communications services, satellites are assigned unique bands of *frequencies* for the reception and retransmission of signals. A *frequency* is defined as the number of times that an alternating current goes through its complete cycle in one second of time. One cycle per second also is called a *Hertz* (Hz), named after the 19th century radio pioneer Heinrich Hertz. One thousand cycles per second is abbreviated as one *kilohertz* (kHz), one million cycles per second, a *Megahertz* (MHz), and one billion cycles per second a *Gigahertz* (GHz).

Each frequency has a specific *wavelength*, the actual distance that the radio wave travels during a single cycle. Each frequency's wavelength can be computed by using one of the following formulas:

Wavelength	=	speed of light/frequency in Hz (a constant)
Wavelength (in meters)	=	300,000,000m per second/ frequency in Hz
Wavelength (in feet)	=	186,000 miles per second/ frequency in Hz

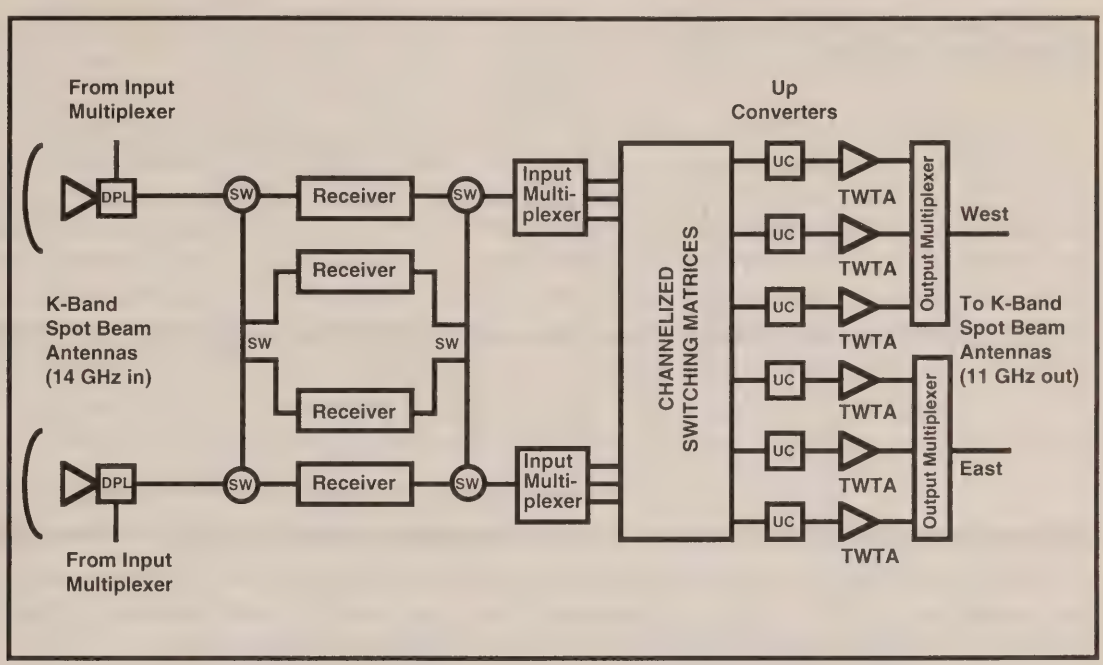


Fig.2-4. Simplified INTELSAT V Ku-band communications system block diagram.

The *electromagnetic spectrum* is the entire continuum of frequencies used to propagate signals through space. Each subset or *band* of this continuum has unique properties. The nature of these properties depends on the actual physical length of the electromagnetic waves as they radiate outward from the signal source. The following description of the properties of different types of radio waves will show why certain frequencies have been set aside for satellite use.

Long and Medium Waves

The very low frequency (VLF) and low frequency (LF) bands between 3 and 300 kHz are called *long waves.* These radio waves are used for communicating with ships at sea. Very long antennas are needed to transmit and receive long wave radio transmissions. The American and Russian navies use long waves to communicate with submerged nuclear submarines because the signals actually can propagate through water.

The medium frequency (MF) bands between 300 kHz and 3 MHz are called *medium waves.* These radio signals are conducted along the Earth's surface over considerable distances. This is why AM broadcast radio stations can reach distant listeners on a regular basis during the evening hours.

Short Waves

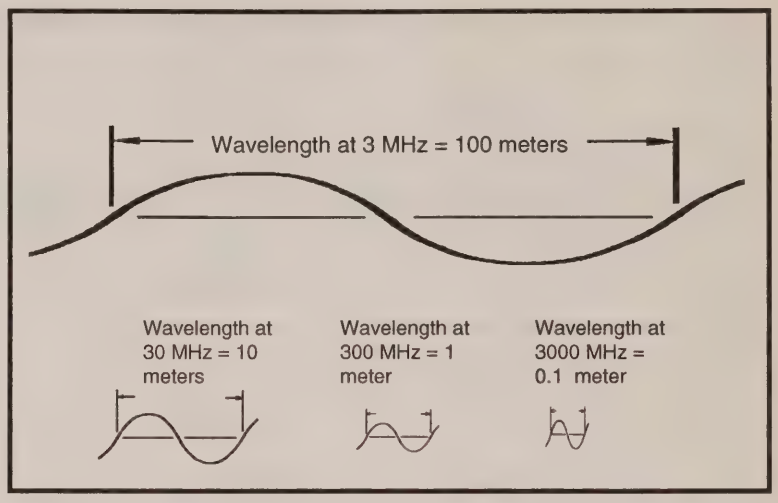
The frequency bands between 3 and 30 MHz are called *short waves.* At predictable periods during each day, short-wave radio signals bounce off the Earth's ionosphere—upper layers of the atmosphere that have been charged electrically by radiation released by solar storms. During daylight hours, and especially during peak periods of solar activity, short wave signals can be transmitted over thousands of miles. Overseas radio broadcasters, shipboard radio operators, amateur radio hobbyists and CB radio enthusiasts transmit and receive short wave radio signals on a fairly reliable basis.

Very High Frequency (VHF) & Ultra High Frequency (UHF) Bands

In the 1940s, the very high frequency (VHF) bands between 30 and 300 MHz were assigned to local U.S. television and radio broadcast stations. On rare occasions, intense Sunspot or meteorological activity cause VHF TV transmissions to travel far beyond their local coverage zones.

In the 1950s, Ultra High Frequencies (UHF) in

Fig.2-5. Relationship between frequency and wavelength.


Wavelength at 3 MHz = 100 meters
Wavelength at 30 MHz = 10 meters
Wavelength at 300 MHz = 1 meter
Wavelength at 3000 MHz = 0.1 meter

the 300 to 3000 MHz range were assigned for the transmission of television because they seldom are affected by ionospheric conditions.

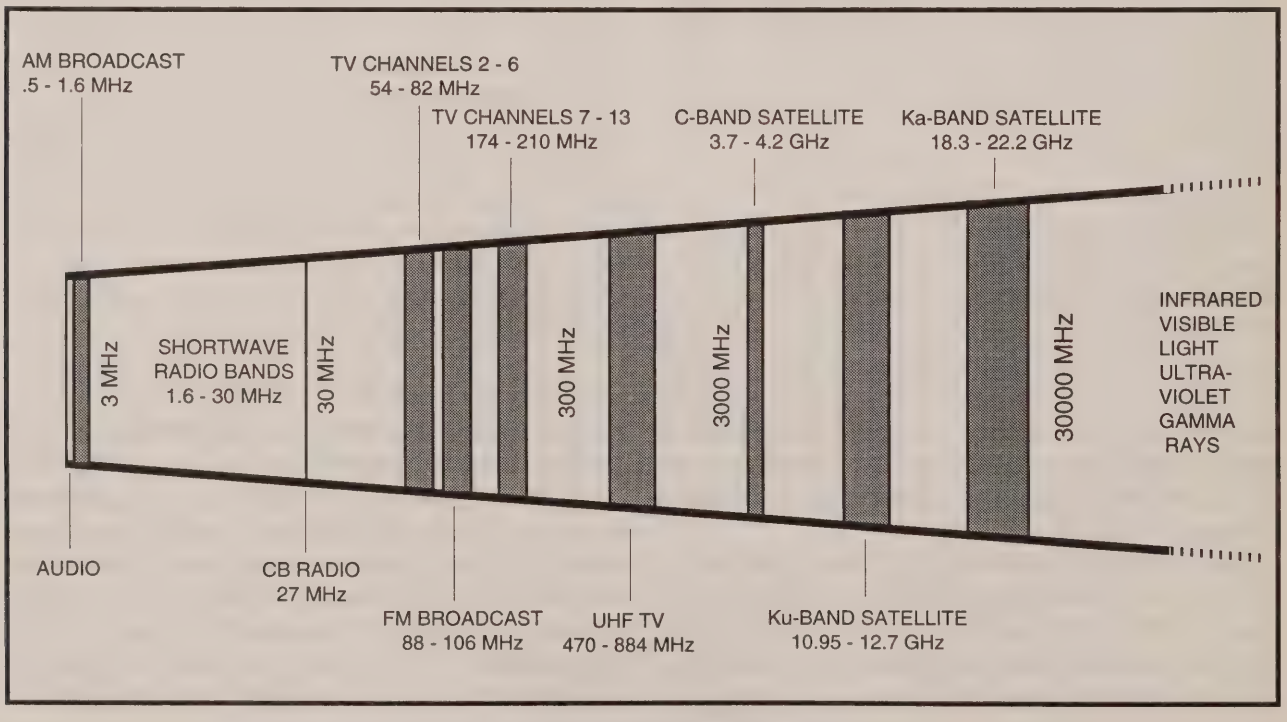
The Super High Frequency Bands

Super high frequencies (SHF) between 3,000 MHz (or 3 GHz) and 30,000 MHz (or 30 GHz) have been allocated for satellite telecommunications purposes. Signals transmitted in the frequency bands between 1 and 50 GHz are known as *microwaves*.

International Telecommunication Union

The International Telecommunication Union—the United Nations' specialized agency for telecommunications—is responsible for the

Fig.2-6. The electromagnetic spectrum (based on FCC frequency assignments for the United States).



assignment of communication frequencies on a worldwide basis. The ITU is comprised of four permanent organs: the General Secretariat, the International Frequency Registration Board (IFRB), the International Radio Consultive Committee (CCIR) and the International Telegraph and Telephone Consultive Committee (CCITT). Of the four ITU organs, it is the task of the IFRB to serve as a clearing house for the assignment of frequencies and orbital slots for domestic, regional, and international telecommunications satellites.

Member nations gain equitable and guaranteed access to the geostationary orbit by registering new satellite systems with the IFRB. The IFRB registration process also helps ensure that potential interference will be minimized between satellites in close proximity.

Fig.2-7. World Satellite Frequency Allocation Chart.

Uplink (GHz)	**Downlink** (GHz)	**Band**[2]	**Category/ITU Region(s)**
6.41 - 6.441	1.53 - 1.544	L	MSS - (Inmarsat)
6.41 - 6.441	1.6265 - 1.6455	L	MSS - (Inmarsat)
13.0 - 13.15[4]	1.545 - 1.559	L	MSS - (U.S. only)
13.2 - 13.25[4]	1.6465 - 1.6605	L	MSS - (U.S. only)
14.0 - 14.20[4]			
5.920 - 6.040	2.540 - 2.655	L	BSS - (Arabsat only)
5.855 - 5.935	2.555 - 2.635	L	BSS - (India only)
5.925 - 6.055[3]	2.535 - 2.655	S	FSS & BSS
5.725 - 5.925	3.4 - 3.7	C	FSS - (USSR & Intelsat)
5.925 - 6.425	3.7 - 4.2	C	FSS
6.425 - 7.075	4.5 - 4.8	C	FSS - WARC 79 expansion[1]
7.9 - 8.4	7.2 - 7.75	X	FSS - (Military, government)
12.75 - 13.25	10.7 - 10.95	Ku	FSS - WARC 79 expansion[1]
14.0 - 14.5	10.95 - 11.2	Ku	FSS - ITU 1 & 3
	11.20 - 11.45	Ku	FSS - WARC ORB 85 expansion
14.0 - 14.5	11.45 - 11.7	Ku	FSS - ITU 1 & 3
14.0 - 14.5	11.70 - 12.2	Ku	FSS - ITU 2
17.3 - 18.1	11.70 - 12.50	Ku	BSS - ITU 1 & 3
(14.5 - 14.8 outside of Europe & Malta)			
17.3 - 17.8	12.20 - 12.75	Ku	BSS - ITU 2
14.0 - 14.25	12.50 - 12.75	Ku	FSS - ITU 1 & 3
	12.75 - 13.25	Ku	FSS - WARC ORB85 expansion[1]
27.0 - 30.0	18.3 - 21.20	Ka	FSS
30.0 - 31.0	21.2 - 22.20	Ka	FSS

(1) The 1985 World Administrative Radio Conference on the Use of the Geostationary Satellite Orbit (WARC ORB 85) recommended that frequencies within these bands should be assigned to individual countries for domestic satellite systems.
(2) The letter designations applied to the above microwave frequency bands have not been officially assigned by the ITU, but rather are popular designations for specific radar bands that have been applied to satellite transmissions as well.
(3) Uplink frequency band used by Arabsat & Insat.
(4) Represents different uplink frequencies to be used by AMSC depending on the orbital location of the satellite.

Ground-based satellite communication facilities transmit signals over an assigned set of "uplink" frequencies. The satellite receives these incoming signals and then retransmits them Earthward to associated receiving stations by means of a second assigned set of "downlink" frequencies. Some satellites are specially constructed to transmit and receive signals via multiple sets of frequency bands—allowing operators to select the most appropriate frequency spectrum for the type of telecommunications traffic being handled.

The International Telecommunication Union has divided the world into three separate regions. ITU Region 1 (ITU 1) includes Europe, Africa and the Middle East; ITU Region 2 (ITU 2) encompasses the Americas; and ITU Region 3 (ITU 3) is comprised of Asia, the Indian subcontinent, and the South Pacific. The preceding frequency allocation chart shows which superhigh frequency bands are assigned for satellite operations in the various ITU regions. Entries without ITU designations are used on a worldwide basis.

The ITU classifies satellite communications services under three general categories. The *Fixed Satellite Service (FSS)* is a private point-to-point communications service not intended for direct reception by the public. The *Broadcast Satellite Service (BSS)* handles telecommunications traffic that is intended for direct reception by the general public. FSS frequency

Fig.2-8. C-Band Fixed Satellite Service Frequencies.

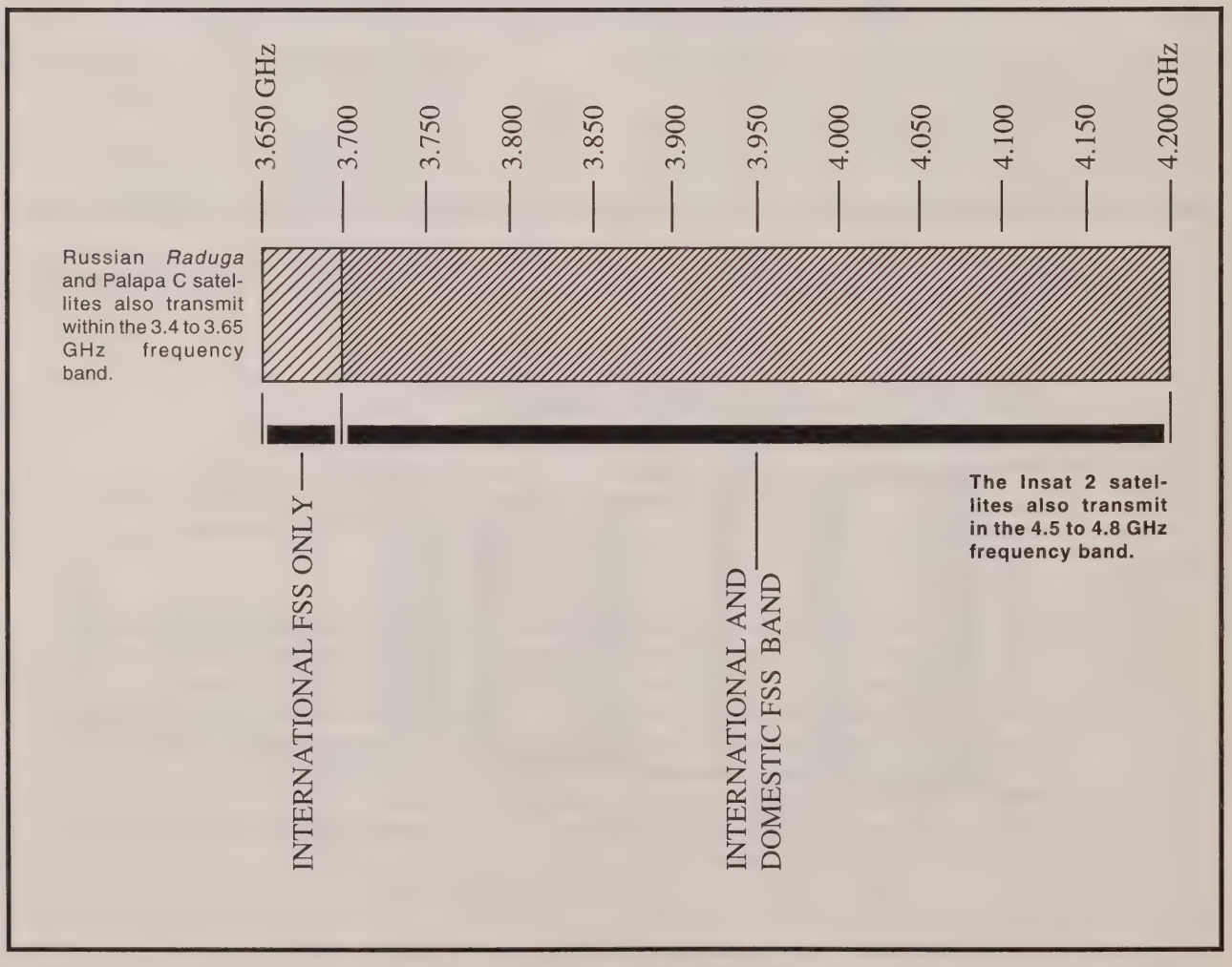


Fig.2-9. Ku-Band Fixed Satellite Service Frequencies for North and South America.

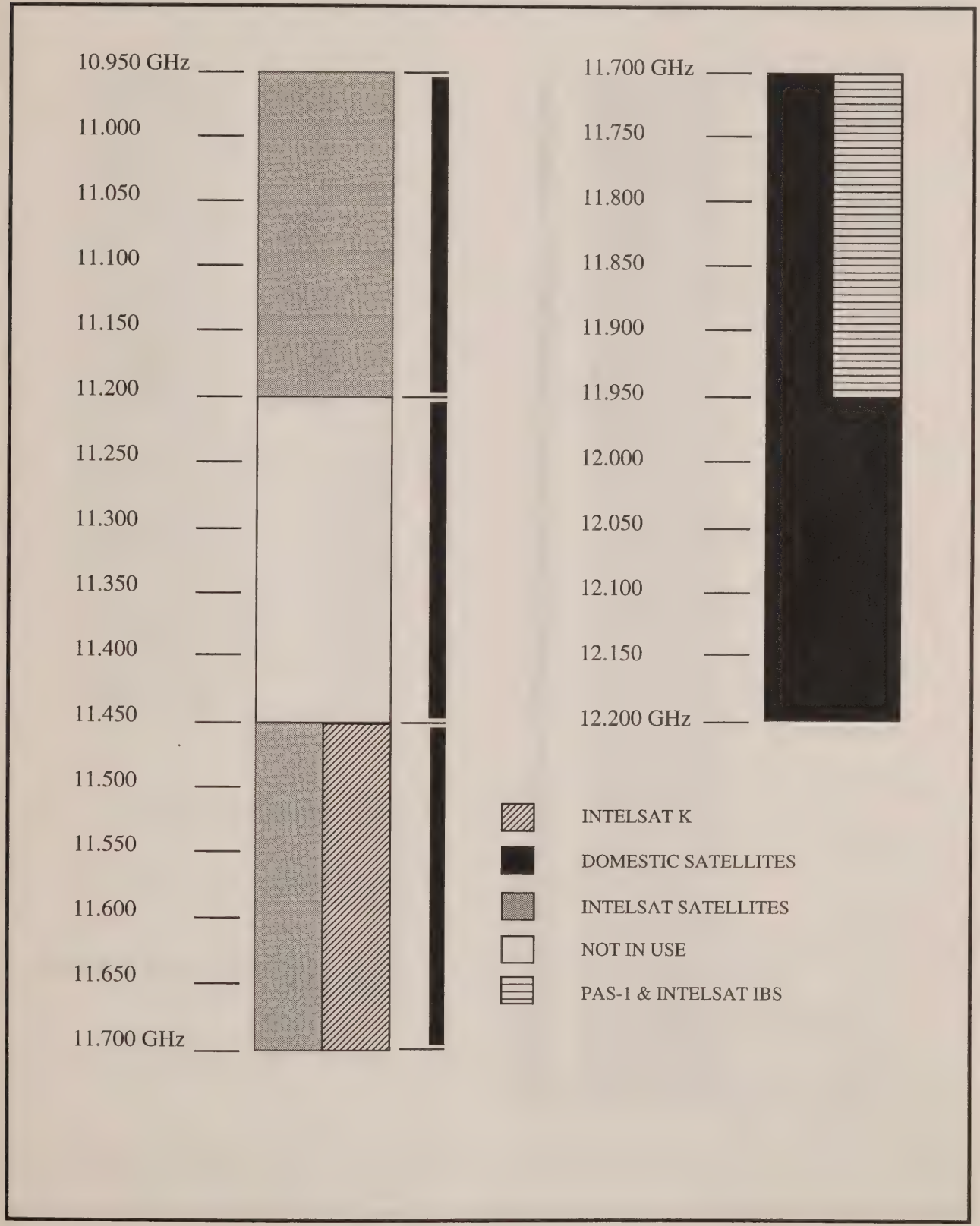


Fig.2-12. Broadcast Satellite Service (BSS) Frequency Assignments.

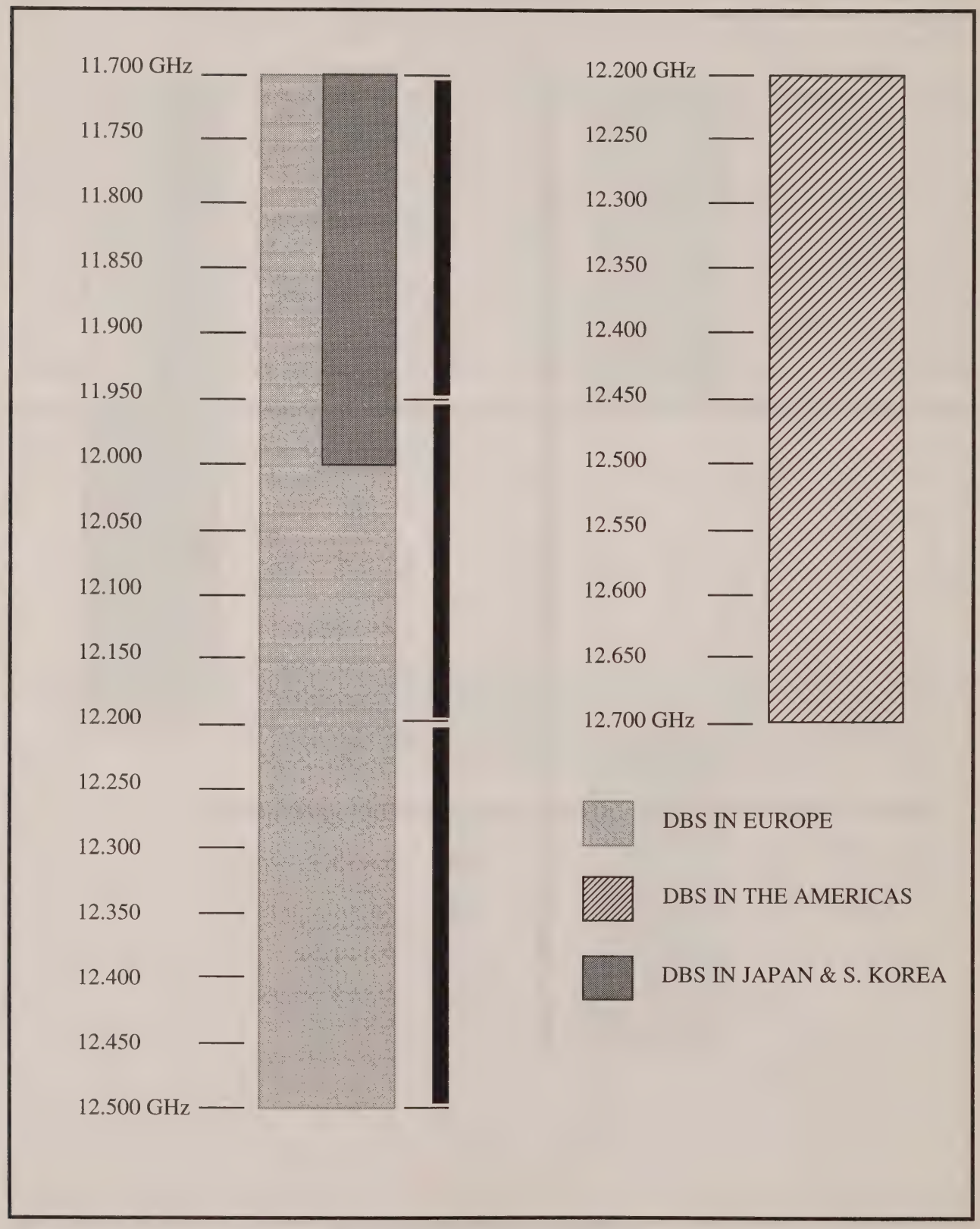
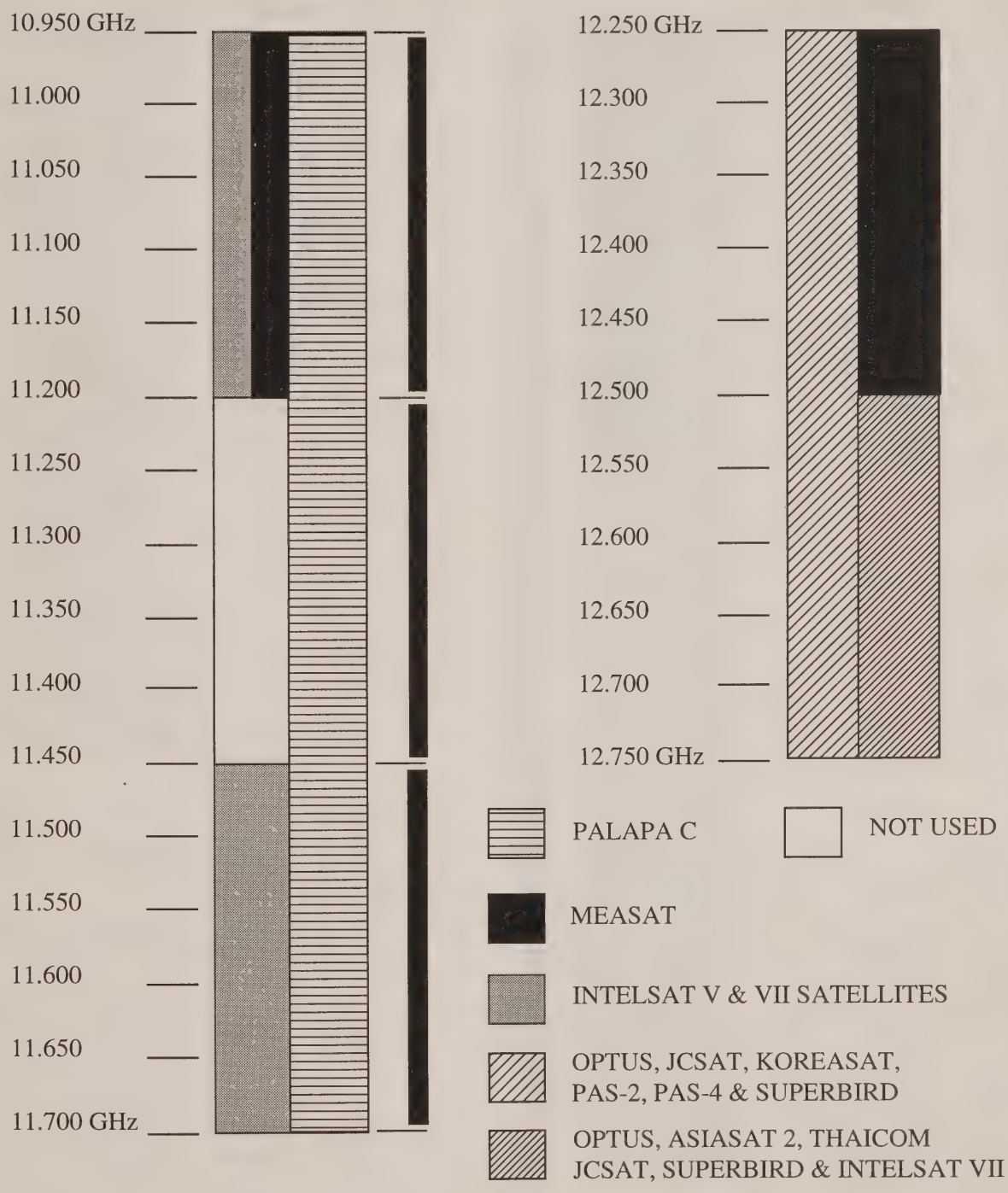
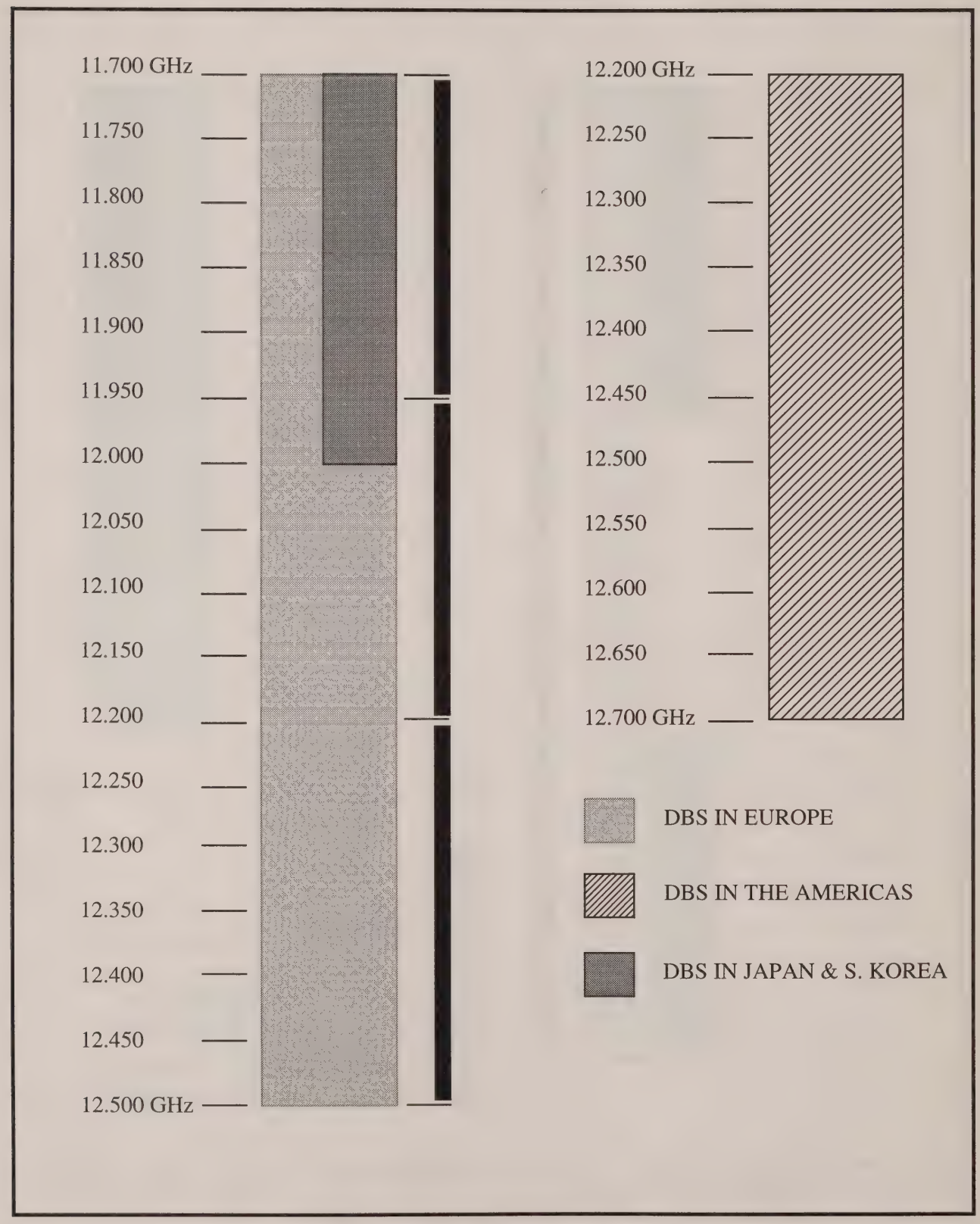


Fig.2-11. Ku-Band Fixed Satellite Service Frequencies for Pacific Rim Countries.



NOTE: CHINASAT 5 (formerly Spacenet I) provides Ku-band Fixed Satellite Service (FSS) into the People's Republic of China using the 11.7 to 12.2 GHz frequency range.

Fig.2-12. Broadcast Satellite Service (BSS) Frequency Assignments.



allocations, however, may be used to transmit direct to home (DTH) signals if approval is granted by the telecommunications authorities of individual nations. *The Mobile Satellite Service (MSS)* relays telecommunications to and from land mobiles, airplanes, ship and sea, and fixed satellite earth stations.

WARC-92 Satellite Frequency Allocations

The 1992 World Administrative Radio Conference (WARC-92) was held in Torremolinos, Spain from February 3 to March 3 of 1992. WARC-92 was attended by more than 1,400 delegates and observers from 127 member countries of the International Telecommunication Union and thirty one international and regional organizations.

The World Administrative Radio Conference operates under the auspices of the International Telecommunication Union (ITU). WARC's decisions act as treaties among nations.

The purpose of WARC-92 primarily was to review the allocation of frequency bands for the high frequency shortwave broadcasting service (HFBC), for the broadcasting satellite service (BSS), for the mobile satellite service (MSS), and for the fixed satellite service (FSS). WARC-92 also considered allocations for space operation, space research services, and new space applications above 20 GHz.

The partial revision of the ITU's Radio Regulations, as put forth in the Final Acts of WARC-92, entered into force on October 12, 1993. However, a number of provisions either came or will come into effect on other dates. For example, interim procedures for the coordination and notification of frequency assignments of certain non-geostationary satellite networks entered into effect on March 4, 1992.

Sound and HDTV Broadcast Satellite Service (BSS)

WARC-92 agreed to establish primary frequency allocations for broadcast satellite service sound (BSS—Sound) in bands near 1.5, 2.3, and 2.6 GHz, pending the convening of another World Administrative Radio Conference no later than 1998 for further planning of the BSS Sound service. No specific bands were allocated for feeder links for BSS—Sound. The BSS Sound frequency allocations will take effect from April 1, 2007.

The Conference was unable to reach a consensus for a unique worldwide frequency allocation for wideband HDTV. ITU Regions 1 and 3 opted for the 21.4 to 22 GHz frequency band while ITU Region 2 selected the 17.3 to 17.8 GHz frequency spectrum. BSS—HDTV feeder links will be provided through new FSS (Earth-to-space) allocations in the 18.1 to 18.4 GHz spectrum worldwide and in the 24.75 to 25.25 GHz frequency range within ITU Regions 2 and 3.

WARC-92 also adopted a resolution calling for a review of the WARC-77 broadcast satellite service (BSS) plans for ITU Region 1 (11.7 to 12.5 GHz) and ITU Region 3 (11.7 to 12.2 GHz). This review will take into account the technological improvements in satellite antennas and receivers which have taken place since the adoption of the WARC-77 plan.

There was an overall perception that a review of the WARC-77 plan would lead to improved use of the BSS spectrum and orbital assignments. This review is expected to culminate in a future WARC Conference with recommendations on how to improve the use of the BSS spectrum to the benefit of Members which do not yet have operational BSS systems while at the same time protecting the rights of existing BSS system operators.

New FSS Ku-band Frequency Allocations

Another major WARC-92 achievement was the worldwide allocation of a new segment of Ku-band uplink frequencies ranging from 13.75 to 14.0 GHz. These frequencies have been allocated to the FSS on a co-primary basis with existing radiolocation services. Criteria for sharing operations within this band of frequencies were developed and an agreement was reached to protect the operations of space research and Earth exploration satellite services—which will retain a secondary status—up to January 1, 2000.

Prior to WARC-92, the 13.75 to 14.0 GHz frequency band was allocated on a primary basis to the radiolocation service and, in a

Fig. 2-13. WARC-92 Satellite Frequency Allocations Chart

Service/Description	Frequencies	Start-up Date
Broadcast Satellite Service (BSS) Sound	1.452~1.492 GHz	April 1, 2007
	2.310~2.360 GHz	
	2.535~2.655 GHz	
Broadcast Satellite Service (BSS) HDTV	21.4~22 GHz (ITU 1 & 3)	April 1, 2007
	17.3~17.8 GHz (ITU 2)	April 1, 2007
Small Low Earth Orbiting Satellites	137~137.025 MHz	October 13, 1993
primary allocation	137.175~137.825 MHz	
primary allocation	148~149.9 MHz	
primary allocation	400.15~401.0 MHz	
secondary allocation	137.025~137.175 MHz	
secondary allocation	137.825~138.0 MHz	
Mobile Satellite Service (MSS)	1.525~1.530 GHz	October 13, 1993
	1.492~1.525 GHz (ITU2)	
Earth-to-space	1.610~1.6265 GHz	
space-to-Earth	2.4835~2.520 GHz	
secondary allocation	1.6138~1.6265 GHz	
primary allocation (ITU 2)	1.675~1.710 GHz	
primary allocation (ITU 2 & 3)	1.6265~1.631 GHz	
New FSS Ku-band Uplink Frequency Band	13.75~14.0 GHz	
Ka-band Frequency Allocations		
Beacon (space-to-Earth primary)	27.500~27.501 GHz	
Beacon (space-to-Earth secondary)	27.501~29.999 GHz	
FSS-primary/MSS-secondary (Earth-to-space)	29.9~30.0 GHz	
	29.5~29.9 GHz	
FSS-primary/MSS-secondary (space-to-Earth)	20.1~20.2 GHz (ITU 2)	
	19.7~20.1 GHz (ITU 2)	

number of countries such as Japan, on a primary basis to the radio navigation service. The band also was allocated on a secondary basis to the space research and Earth exploration satellite services. Moreover, the band was allocated to the fixed and mobile services in a number of countries on a primary basis, and to the standard frequency and time signal satellite service (Earth-to-space) on a secondary basis.

Sharing criteria between the FSS and the radiolocation and radionavigation services were developed to permit the satisfactory operation of these services without the need for further inter-service coordination. These criteria included limitations on uplink EIRP and the exclusion of VSAT operations. A minimum antenna diameter of 4.5 meters for FSS earth stations was included.

New Ka-band Allocations

At Ka-band (30/20 GHz), two significant issues were addressed by WARC-92: the introduction of a downlink allocation for beacon transmissions in the uplink frequency range of 27.5 to 30 GHz to facilitate the operation of uplink power control for systems in these bands and a new "General Satellite Service" (GSS) that would have provided capacity for personal access communications using fixed and mobile

earth stations in the Ka-band.

WARC-92 approved the following beacon transmission allocations to the FSS in the space-to-Earth direction: the bands 27.500 to 27.501 GHz and 29.999 to 30.0 GHz on a primary basis and the band 27.501 to 29.999 GHz on a secondary basis. However, the Conference decided not to proceed with the establishment of a new service category known as the General Satellite Service (GSS) in the language of the ITU's Radio Regulations.

To facilitate the introduction of new applications envisioned by GSS, the Conference did upgrade the existing secondary allocations of the MSS to co-primary status with FSS in the bands 29.9 to 30 GHz (Earth-to-space) and 20.1 to 20.2 GHz (space-to-Earth) in all three ITU Regions, and in the 29.5 to 29.9 GHz (Earth-to-space) and 19.7 to 20.1 GHz (space-to-Earth) frequency bands in ITU Region 2. Moreover, several footnotes to the WARC-92 agreement were added in an attempt to facilitate continued FSS Ka-band applications for which this frequency spectrum previously had been allocated on an exclusive basis and to minimize the sharing difficulties between FSS and the MSS systems which will begin using these spectrums at some point in the future.

WARC-92 & the Geostationary Orbit

The Conference also took steps to clarify the definition of the geostationary satellite orbit (GSO) and end the ambiguity on the extent to which an inclined satellite orbit would be accepted as a GSO. WARC-92 defined the GSO as "the orbit of a geosynchronous satellite which the circular and direct orbit lies in the plane of the Earth's equator." Moreover, WARC-92 examined the maximum allowable inclination angle of satellite networks using slightly inclined geostationary satellite orbits. While WARC-92 decided not to adopt any specific values of maximum inclination, the Conference noted that from a technical standpoint, in frequency bands which are not shared with terrestrial systems, geostationary satellites can operate until reaching a natural inclination limit of 15 degrees without causing significant interference to other satellite networks. However, in frequency bands shared with terrestrial systems, WARC-92 noted that the natural limit may not be acceptable and that the maximum inclination angle has yet to be defined.

Satellite Antenna Subsystem

All telecommunications satellites carry antenna payloads that receive and retransmit communication signals. Domestic satellites

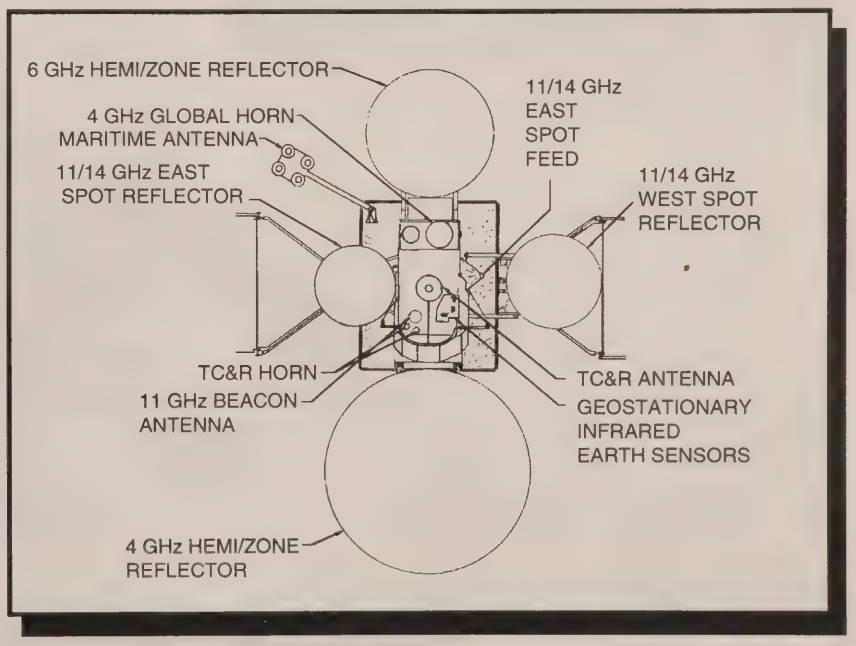

6 GHz HEMI/ZONE REFLECTOR
4 GHz GLOBAL HORN MARITIME ANTENNA
11/14 GHz EAST SPOT REFLECTOR
11/14 GHz EAST SPOT FEED
11/14 GHz WEST SPOT REFLECTOR
TC&R HORN
11 GHz BEACON ANTENNA
TC&R ANTENNA
GEOSTATIONARY INFRARED EARTH SENSORS
4 GHz HEMI/ZONE REFLECTOR

Fig.2-14. INTELSAT V antenna array.

commonly have one or more spot beam reflectors which concentrate most of the available energy onto the territories of an individual nation. As global telecommunications providers, international satellites commonly carry more complex antenna arrays. The dual-band (C/Ku) INTELSAT V and VI series satellites, for example, carry several different antennas. Each antenna is capable of generating unique global, hemispheric, zone, and spot beam footprints. Spatial isolation between the East and West hemispheric, zone and spot beam pairs allows each spacecraft to transmit in both directions using identical transponder frequencies.

The spectrum of frequencies available for satellite communications is limited. Satellites obtain the most efficient use of this limited resource through the simultaneous transmission of two sets of signals that share the identical frequency band. Interference between the two sets of signals is minimized through the use of opposite or *orthogonal* senses of polarity.

Most domestic satellite antennas use *linear polarization* to simultaneously transmit signals in vertical and horizontal planes. Many international satellites—as well as all DBS satellites—transmit their signals in a spiralling pattern called *circular polarization*, where the electromagnetic field of the signal rotates in either a clockwise or counterclockwise direction.

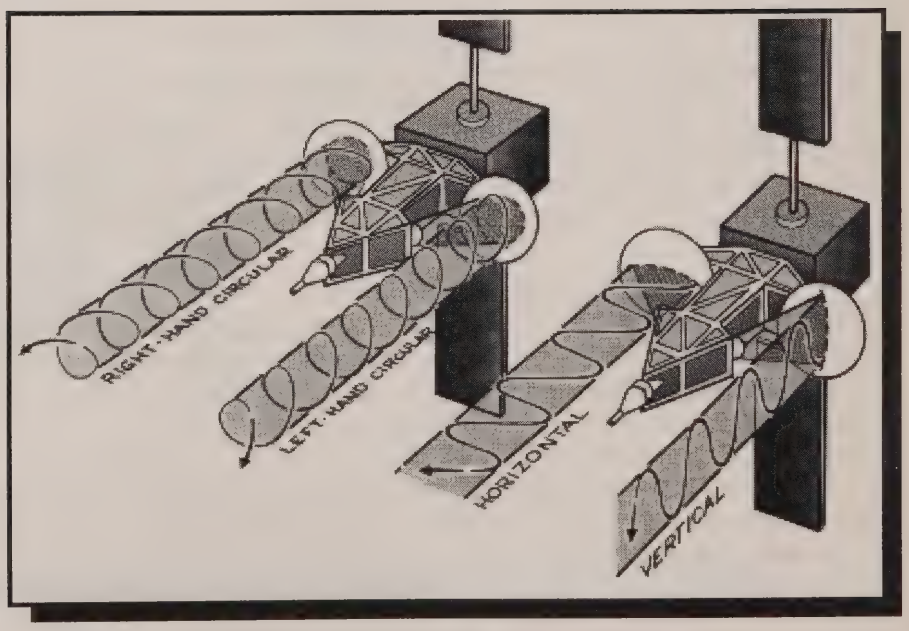


Fig.2-15.
Satellite signal polarizations.

Chapter 3

World Video Standards

Earth station operators who attempt to receive signals relayed by international satellites will find that several video standards are used. These may vary from region to region or even country to country. Earth station equipment must be compatible with these international standards to receive or record high-quality, full-color pictures.

Every TV camera converts the televised scene into several hundred separate horizontal lines. Early TV inventors such as Philo T. Farnsworth and Vladimir Zworykin found that the more lines per screen, the greater the resolution or clarity of the video image. An individual line consists of numerous dots—called *pixels*—each with its own brightness level.

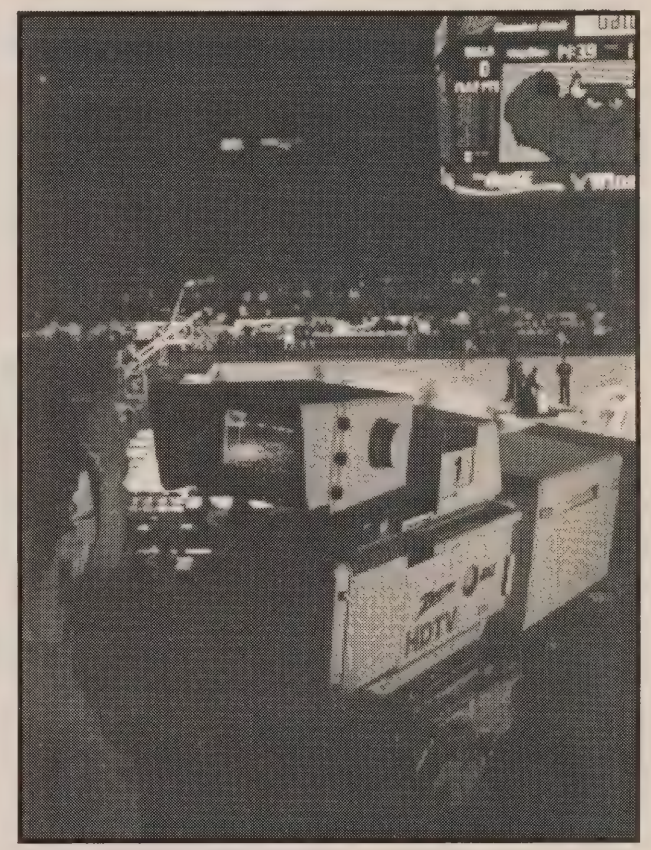


Fig. 3-1. Every TV camera converts the image into hundreds of separate horizontal lines. (Courtesy of Zenith.)

Monochrome Standards

In 1928, Philo T. Farnsworth transmitted the world's first TV signals (if we exclude mechanically scanned systems) from his lab on Green Street in San Francisco to stunned viewers at the S. F. Merchant Exchange, more than a mile away. Early American black-and-white or *monochrome* television transmissions used either 343- or 441-line video fields transmitted at 30 frames per second. It soon became apparent that the quality of these transmissions left much to be desired.

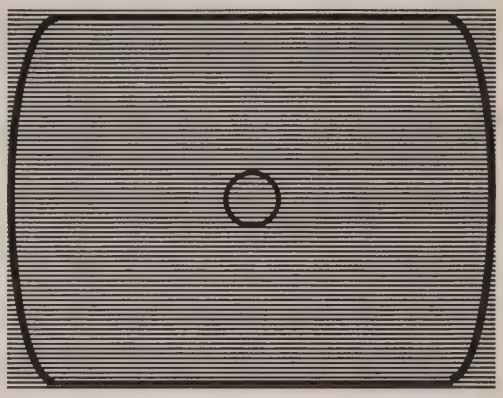
On July 31, 1940, the NTSC (National Television Standards Committee), a group of 168 U.S. electronics specialists, was formed to establish a new video standard. On March 8, 1941, the Federal Communications Commission (FCC) approved the NTSC recommendation for monochrome transmissions.

The NTSC standard consists of 525 scanning lines per "picture" frame. Flashed at a rate of 30 frames per second, each NTSC frame has two alternating or "interlaced" fields consisting of 262 and 1/2 lines each. The speed at which the fields are transmitted, however, is so great that the eye perceives the image as a whole rather than as two separate components.

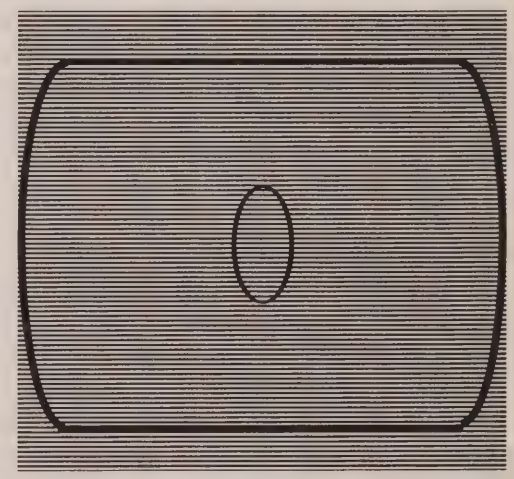
Meanwhile, several other video standards were developed across the Atlantic. In 1937, the British Postmaster General approved a standard developed by EMI-Marconi for 405-line video at 25 frames per second. When the 405-line screen proved unsatisfactory, the British adopted a second standard. This standard specified a 625-line screen at 25 frames per second. Both standards coexisted in the United Kingdom until a few years ago, when the government abandoned the older 405-line system.

The French found even the 625-line screen

a). Standard 525-line raster viewed on a 525-line, 60-Hz TV set.



b). A 625-line raster viewed on a 525-line, 60-Hz TV set after adjustment of the vertical hold control to lock field scan. However, the video is distorted, causing shapes to appear tall or skinny.



c). An adjustment to the TV set's linearity control is needed to reduce the picture height so that the correct aspect ratio of the 625-line signal can be properly displayed on a 525-line screen.

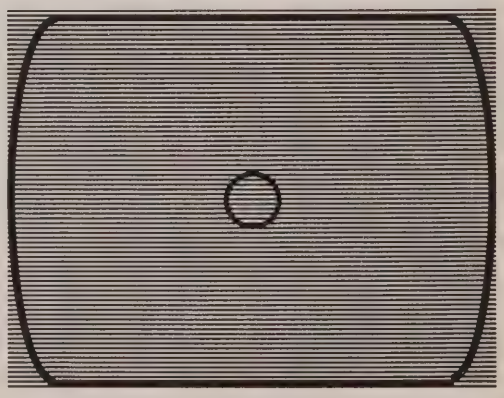


*Fig.3-2. The picture height must be adjusted whenever viewing a 625-line transmission on a 525-line TV set. (Derived from the **International Satellite TV Reception Guidebook** by Stephen J. Birkill © 1982. All rights reserved.)*

inadequate for their purposes, and developed a unique 819-line standard. However, no other country in the world followed the French lead; France eventually opted for compatibility with its European neighbors and adopted its current 625-line standard. Most other Western European countries also eventually accepted the 625-line standard, with minor variations in video bandwidth and the degree of separation in frequency between the video waveform and the accompanying sound signal.

Any regular television set will display at least a monochrome picture of an unencrypted analog (non-digital) TV signal, regardless of the video standard used to broadcast it. A 625- line transmission can be squeezed onto a 525-line screen simply by adjusting the vertical linearity. Without this adjustment, the top and bottom of the 625-line video will extend beyond the coverage area of the screen. Because of the difference between 25 and 30 frames per second, it also is necessary to adjust the vertical hold control to stop the picture from "rolling."

Video Color Standards

Not until the late 1940s was the transmission of video signals in full color technically possible. In 1950, the U.S. Federal Communications Commission (FCC) approved a plan by the CBS TV network for a separate color television standard. This standard used a 405-line frame switched at the rate of 24 frames per second. However, millions of existing black-and-white sets would have been incompatible with the new standard. The FCC reconvened the National Television Standards Committee to solve the dilemma.

Instead of the proposed CBS standard, the NTSC recommended an alternative color standard totally compatible with the existing monochrome system. The new standard used a chroma color *subcarrier frequency,* or secondary frequency, to carry the color information, inserted within the video signal passband at 3.58 MHz. To determine the correct color saturation level of the NTSC video, the phase of the subcarrier signal was compared with a reference signal generated by a circuit inside the television. The instantaneous amplitude of the chroma subcarrier determined the saturation level of the color, and the phase of the subcarrier determined the shade of color or tint. After the United States accepted NTSC, it also was adopted by most countries in the Western hemisphere, as well as Japan, Myanmar, South Korea, Taiwan and the Philippines.

The NTSC color standard was a technical compromise that sacrificed some performance in order to achieve a system that could transmit video to both color and monochrome TV sets. However, there were distinct drawbacks to this compromise. Whenever the luminance (brightness) and chrominance (color) information are combined into a composite video signal, this mixing of signals generates unwanted interference byproducts called "artifacts" which act to limit the overall quality of the picture.

Engineers in several Western European countries were aware that any phase errors introduced during the propagation of the NTSC signals resulted in uneven color reproduction. This flaw caused many critics of the American color system to claim that NTSC actually stood for "Never Twice the Same Color."

French engineers eliminated the phase error altogether by using frequency modulation (FM) instead of amplitude modulation (AM) to transmit the color information. Before transmission, they separated the color information into reds and blues. This information then was sent by alternating two color subcarriers, red at 4.40625 MHz and blue at 4.250000 MHz. The color information contained in the alternate lines was recombined at the TV set using a memory circuit included in the design. Called Séquence Couleur `a Mémoire (Color Sequence with Memory), the SECAM method provides faithful color reproduction. Besides France, more than 20 other countries, including several in Eastern Europe, have adopted SECAM.

Unfortunately, production in the SECAM standard proved to be a veritable nightmare down the road because of its inability to accommodate the complicated special effects, fades and wipes that are universally used in broadcasting today. In fact, most countries that now use the SECAM video standard actually first produce their TV programs in PAL—a video standard

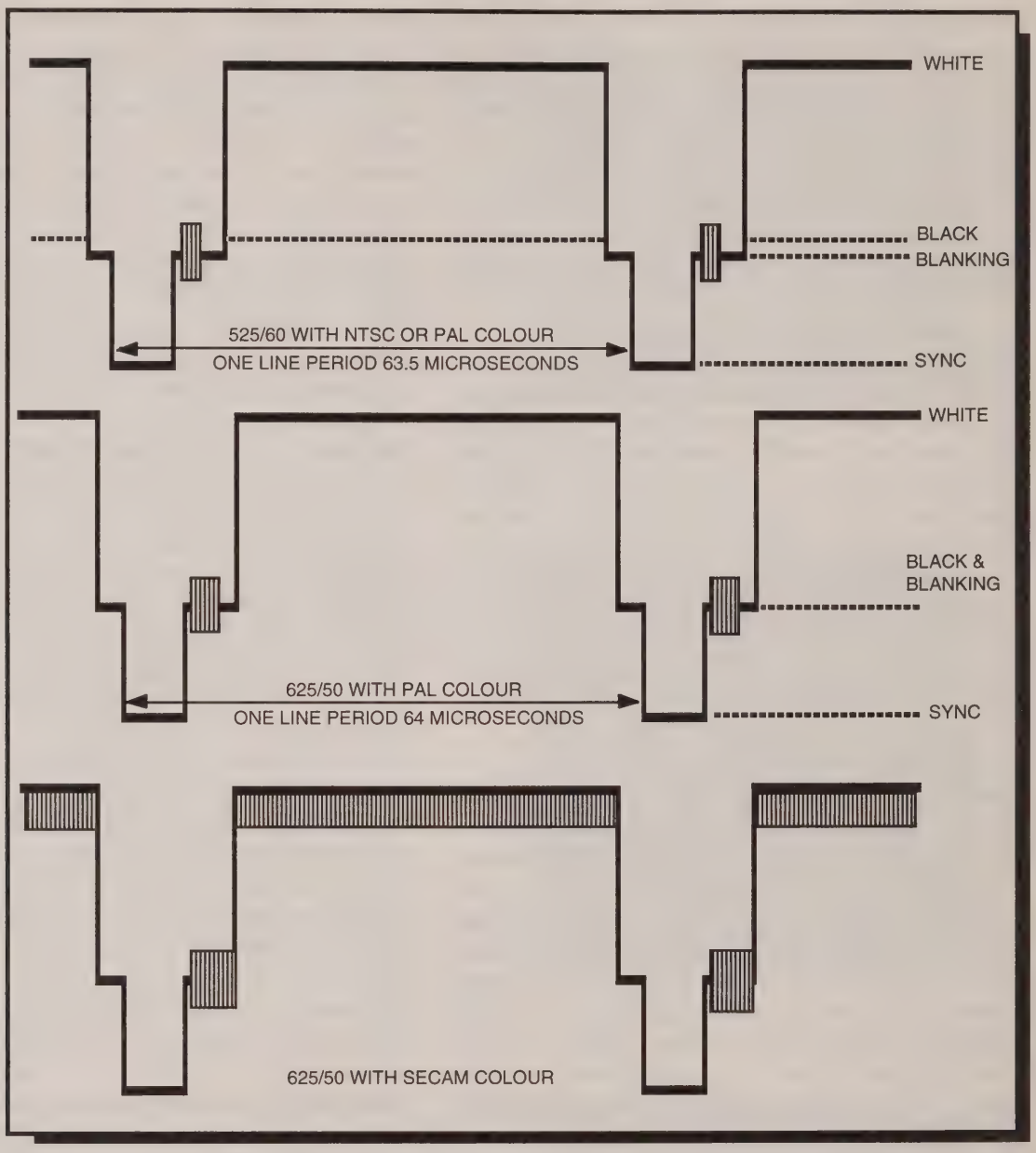


*Fig.3-3. Video Line Frequency Waveforms. (Derived from the **International Satellite TV Reception Guidebook** by Stephen J. Birkill. ©1982. All rights reserved.)*

developed by Germany—and then convert the PAL signals to SECAM just prior to transmission. This has caused American critics to derisively refer to SECAM as a "System Essentially Contrary to the American Method!"

Germany's Telefunken developed an alternative standard that minimized the phase error problems associated with NTSC while avoiding SECAM's production problems. Telefunken found that inverting the phase errors of the color signal by 180 degrees on alternate lines partially cancelled out the phase errors accompanying the signal. Today, *phase alteration by line* (PAL) is the video standard used by more than 40 countries around the world. Like NTSC, PAL also uses a color subcarrier frequency, but one that is at 4.43 MHz. The PAL color subcarrier is inserted into the composite video signal in a way that eliminates the distortions to the video image commonly found with NTSC. Engineers dissatisfied with both NTSC and SECAM dubbed PAL "Peace At Last."

International Satellite Video Standards

Although receiving international video transmissions in monochrome is a simple affair, decoding the various color standards used around the world can be a nightmare. Multiple video standards not only pose problems for international earth station operators, they also create huge obstacles for broadcasters. Exchanging programs with countries using incompatible color standards requires expensive equipment for converting video from one color standard to another. The many different video standards also cause big problems for those who would like to view videocassettes taped in countries with incompatible color video standards.

Many different color video standards are used for TV transmissions carried by INTELSAT, Intersputnik, and Eutelsat satellites. INTELSAT alone transmits TV services on behalf of more than forty member countries around the world. These countries all use variations of PAL, SECAM, or NTSC. In addition, the domestic satellite systems of various nations use a mishmash of color standards for TV. International news feeds that crisscross the world's oceans by way of the INTELSAT Primary and Major Path satellites also display most variations of the main NTSC, PAL, and SECAM standards. One moment a viewer may be watching a news feed in PAL from WTN or Reuters TV, and the next moment a CNN feed in NTSC, or perhaps a French news feed in 625-line SECAM.

Earth station owners with access to the Gorizont (Russian for "Horizon") satellite at 14 degrees West Longitude will see SECAM transmissions from various Eastern European countries and NTSC signals from Cuba or the United States. The Palapa satellites carry transmissions from Indonesia, Malaysia, and Thailand in PAL, and video from the Philippines in NTSC. (See Appendix B for a complete listing of standards used around the world.)

A multistandard monitor or television is necessary to receive NTSC, PAL, and SECAM formats in true color on a single set. Multistandard equipment is available from major TV manufacturers, including Sony, Panasonic, Hitachi, JVC, Telefunken, and Barco. When selecting a multistandard set, make sure that the unit has 3.58 NTSC. A few units come with 4.43 NTSC only, which means regular color NTSC programing will appear in black and white. Most multistandard sets have an automatic color standards selection feature that automatically picks the correct standard. Many units also

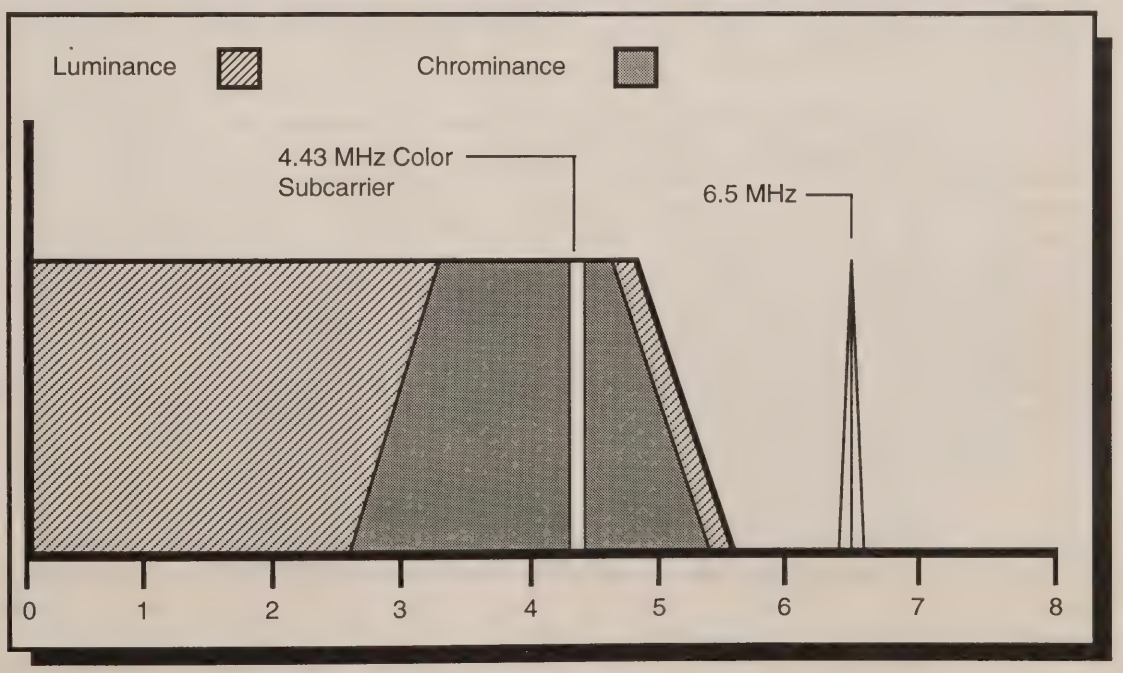


Fig.3-4. PAL 625-line satellite baseband spectra with typical audio subcarriers. (Note that Argentina's 625-line PAL-N video standard uses a 3.58 MHz color subcarrier.)

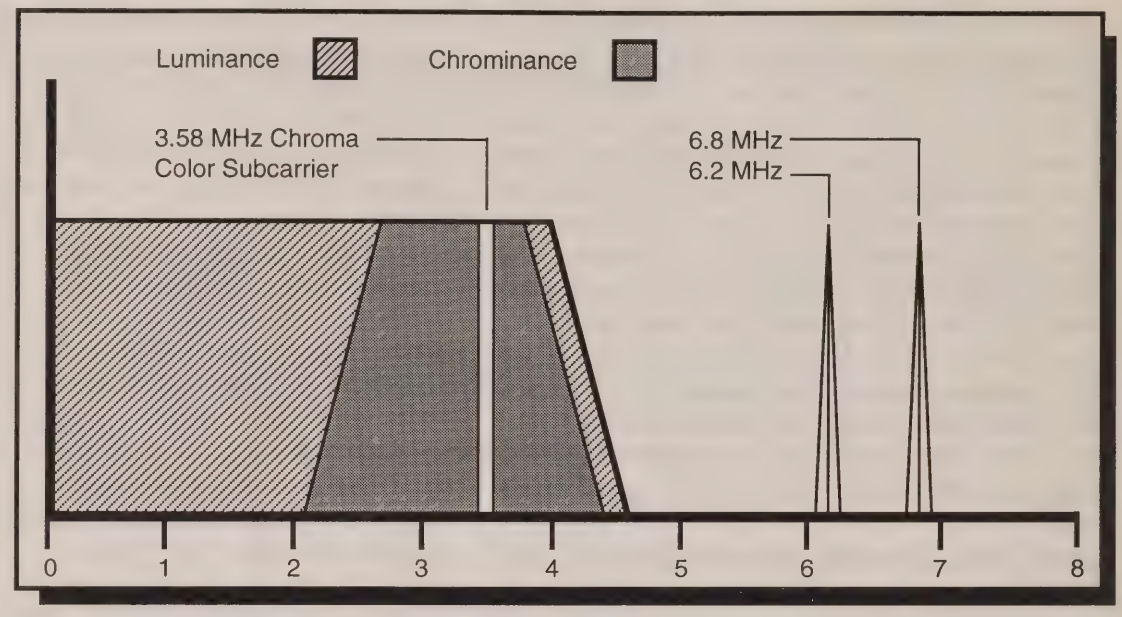


Fig.3-5. NTSC 525-line satellite baseband spectra with typical audio subcarriers. (Note that Brazil's 525-line PAL-M video standard modulates a 3.58 MHz color subcarrier using the PAL modulation technique.)

have either switch-selectable or automatic-selection features for 110 or 220 volts AC. This is useful if the equipment is destined to travel across national borders.

Readers who want to access Argentine or Brazilian satellite video services will find that most multistandard TV monitors are not designed for the particular variations of the PAL video standard used by these countries. Unless the multistandard monitor has been specifically designed to receive PAL M or N, satellite transmissions from Brazil and Argentina will appear only in black and white.

The companies previously mentioned as manufacturers of multistandard monitors also make multistandard videocassette recorders. When purchasing one of these, be sure that the unit can record and play back in all standards. Some VCRs will play back tapes prerecorded in any standard, but do not have the right circuitry to record all standards. Since you may wish to videotape in PAL, SECAM, or NTSC, be sure your equipment is compatible.

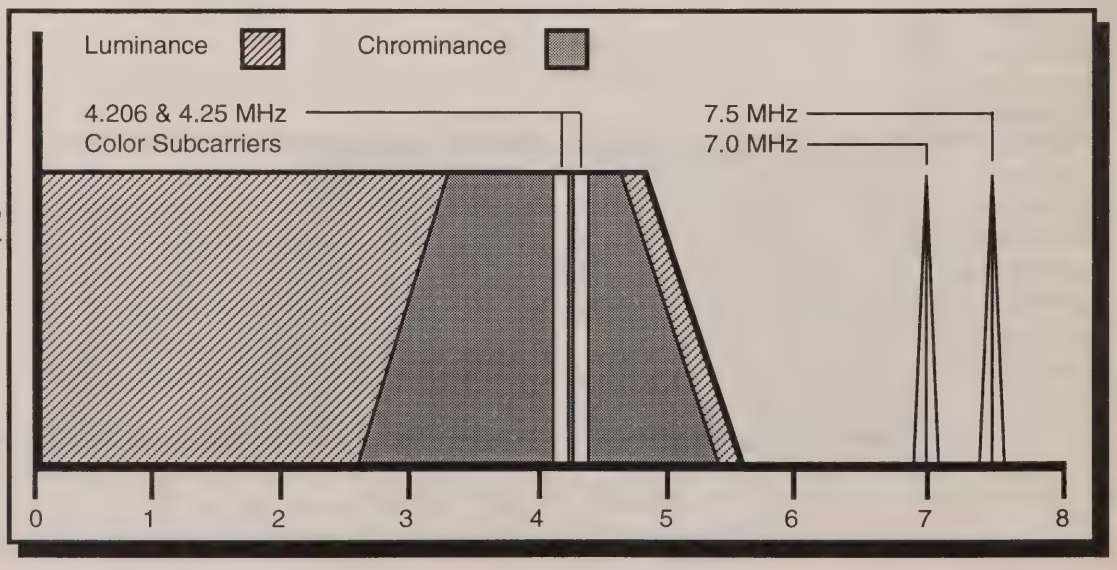


Fig.3-6. SECAM 625-line satellite baseband spectra with typical 7 and 7.5 MHz audio subcarriers for the Russian satellites.

Standards Conversion VCRs

Other companies have introduced special VCRs which can record PAL or SECAM video signals and display them on the screen of most TV/monitors. Some units also feature a built-in option which will allow video signals to be transcoded from PAL or SECAM to NTSC from an external source, including a satellite TV receiver. One simply connects the audio and video output from the satellite receiver to the input of the standards converting VCR to either view satellite programs or record them in their original NTSC, PAL or SECAM format for later playback on most NTSC TV sets.

Low Cost Digital Standards Converters

Many colleges and universities are extremely interested in using foreign satellite TV signals as part of their educational curriculum. For example, Russian language, social studies and political science classrooms at institutions such as Columbia University, the U.S. Naval Academy, Creighton University, and the University of Virginia already tune in via satellite to the most recent developments in the Commonwealth of Independent States.

The major problem that colleges face when installing an international satellite system is how to route the signals to distant classrooms and dormitories. The Russian SECAM signals, for example, cannot be placed on a campus cable system without first being converted to the NTSC video standard.

Until recently, a digital standards converter capable of converting PAL or SECAM to NTSC was very expensive, with the cost ranging from US$ 50,000 to US$ 100,000. In recent years, however, several manufacturers have introduced less expensive digital Standards Converters for under US$ 12,000.

Cinemascopic TV Transmission Format

In 1991, French, Italian, and Dutch satellite TV programmers began transmitting video in a wide screen format that captures the full impact of films and sports events. The European D-MAC and D2-MAC transmission standards have the ability to transmit pictures in a cinemascopic format that is one-third wider than the pictures viewed on conventional TV sets. For the first time, several European companies exhibited MAC-compatible wide screen TV sets that will be introduced later this year to coincide with the inception of wide screen TV broadcasts by the TV-Sat and TDF satellites.

HDTV: On the Threshold of a Dream?

In 1995, the U.S. Federal Communications Commission is scheduled to conclude a rulemaking proceeding that would approve the performance specifications for a new high definition television (HDTV) system that will serve as a new standard in American TV broadcasting well into the 21st century. If previous international decisions concerning TV standards are any indication, the FCC approved HDTV system also will serve as the officially sanctioned standard for many other countries around the world. Although the HDTV standard eventually selected by the Commission will be for terrestrial TV transmissions, the proliferation of HDTV equipment that will occur will make the selected system the de-facto HDTV standard for all VCRs, satellite TV receiving systems and cable systems as well.

High definition television promises to enhance the quality of both the sound and the images to be displayed on millions of TV sets around the world. HDTV images will present up to twice the number of active lines (1080 versus 483) over what conventional TV pictures provide today. The video image will consist of finer-grained pictures with a sharpness that approaches the clarity of 35 millimeter film.

Moreover, the color fidelity of HDTV pictures also will undergo a dramatic improvement. Early foreign TV critics derided the U.S. color TV system adopted by America's National Television Standards Committee (NTSC) by saying that NTSC really stood for "never twice the same color". The new HDTV standard will accurately portray all the colors of the original image without viewers scrambling to adjust the tint controls on their TV sets.

HDTV pictures will be delivered in a wide-screen 16:9 aspect ratio which will more faithfully reproduce the cinemascopic dimensions in which almost all movies are originally filmed.

Sports events also will benefit from the wider field of view, so that TV viewers can take in more of the action without relying on the camera's panning of the scene to include the entire field of play into the more limited display area used by today's 4:3 aspect ratio TV sets. Viewers also will be able to watch an HDTV screen from a wider angle without it appreciably affecting the dramatic impact or the sense of immediacy of the programming.

Observational studies conducted during the 1970s by the Scientific Research Laboratories of Nippon Hoso Kyokai (NHK)—the Japanese Broadcasting Corporation—produced hard data showing that HDTV generates several beneficial psychological effects. As the picture frame widens, the existence of the display screen becomes less noticeable and the picture content subjectively appears to have more depth. Changes in the movement of objects also demonstrably affects the physical balance of the viewer, lending a further sense of realism. HDTV has about five times the visual information as NTSC, so the HDTV picture actually saturates the visual capacity of the viewer, thereby increasing viewer involvement.

The sound fidelity of today's NTSC stereo transmissions is deficient when compared to all-digital audio delivery systems. The NTSC sound channel does not provide enough bandwidth to faithfully reproduce the entire sound spectrum. Future HDTV systems, however, will use digital audio modulation techniques to broadcast TV programs in stereo with compact disc quality, five-channel surround sound. Similar advanced digital transmission techniques already are used by today's compact and laser disc players to achieve an excellent dynamic range and virtual noise-free response.

The Digital Aspects of HDTV

The HDTV standard adopted by the FCC will be an all-digital delivery system. The adoption of digital transmission techniques for video delivery has been a long time in coming. Until fairly recently, digital representations of visual information required far more bandwidth than their analog counterparts. HDTV video signals which formerly required one or more satellite transponders to transmit a single TV broadcast can now be digitally compressed to fit into the standard bandwidths already used to transmit TV signals through the air, over cable, or via satellite. (See Chapter Five for further information on Digital Video Compression.)

The all-digital HDTV standard also will take advantage of sophisticated digital filtering and error correction techniques, which will allow each TV set to detect and "mask" out noise, "ghosting", electrical interference from automobiles and electronic appliances, and other visual impairments which have long afflicted conventional TV viewing. An all-digital HDTV system also will be able to deliver ancillary services such as addressable transmissions of auxiliary audio and data services. These secondary services will be delivered direct to the home via the same bit stream which carries the TV sound and picture information, making HDTV a key enabling technilogy for the National Information Infrastructure.

The FCC To Support A Simulcast System

In 1990, the FCC announced its support for a "simulcast" system when HDTV is introduced by terrestrial broadcasters later in the decade. In a simulcast system, existing NTSC television stations would continue to broadcast as they have in the past. Newly licensed HDTV stations would broadcast simultaneously on currently unusable TV channels.

To prevent interference in today's analog terrestrial TV broadcasting environment, channels are left unoccupied within each major TV coverage area to prevent adjacent channels from interfering with each other. New all-digital HDTV services, however, will be able to occupy these currently unused channels without causing interference to coexisting analog TV services on adjacent channels. In this way, both standard NTSC and HDTV broadcast services can be offered simultaneously in every major TV market in the United States without requiring the assignment of new channel capacity for the new transmission medium. For the first time, every TV channel will be available for use in each TV market, creating a higher level of program diversity than ever before available.

Both NTSC and the HDTV signals will get equal billing on the air, although only TV sets equipped with HDTV circuitry will receive the HDTV broadcasts. Adoption of the simulcast standard will prevent the early obsoletion of the 200 million NTSC TV sets in use today.

In September of 1992, the FCC ruled that terrestrial TV broadcasters will be given six years to begin broadcasting in HDTV after receiving their HDTV construction permits from the Commission. Local TV stations which are awarded an HDTV channel will not be required to simulcast any of their regular programming during the first year of operation. However, 50 percent of a station's regular programming must be simulcast in HDTV during the second year, and 100 percent of its regular programming in HDTV by the end of the six-year construction period.

The FCC also ruled that the major broadcast networks can provide local affiliates with programming produced exclusively for the new HDTV market. This decision was devised as an incentive to get consumers to purchase the required hardware to receive programming which otherwise would be unavailable.

ACATS and the Grand Alliance

In 1987, at the request of U.S. broadcasters, the FCC established a U.S. Advisory Committee on Advanced Television Service (ACATS) for the purpose of recommending a broadcast standard for HDTV transmissions in the United States. ACATS initially evaluated twenty three proposals for HDTV and selected six systems for testing. These six systems—four of which were all-digital—underwent extensive testing in 1991 and 1992 overseen by the ACATS at the Advanced Television Test Center (assisted by Cable Television Laboratories, Inc. of Boulder, Colorado) and at the Advanced Television Evaluation Laboratory in Ottawa Canada.

Following the completion of testing, ACATS elected in February of 1993 to limit further consideration of proposed HDTV systems to the three proponents who had built all-digital systems: General Instrument and Massachucetts Institute of Technology (two jointly developed

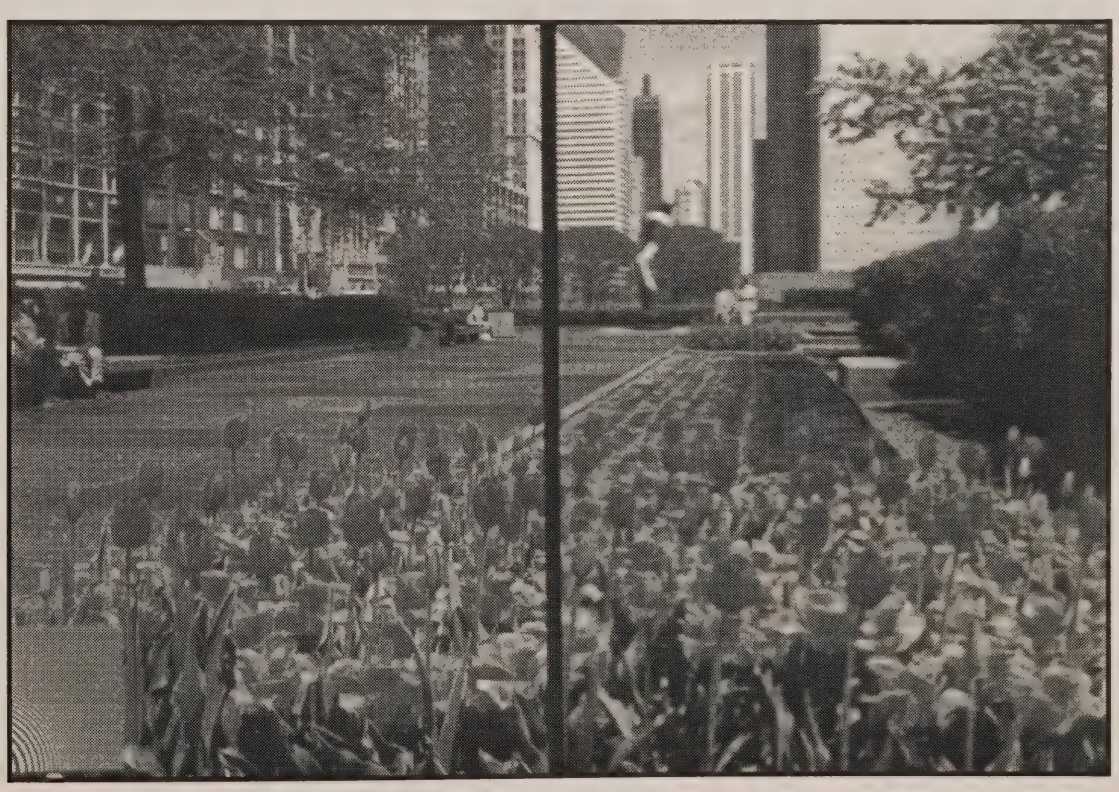
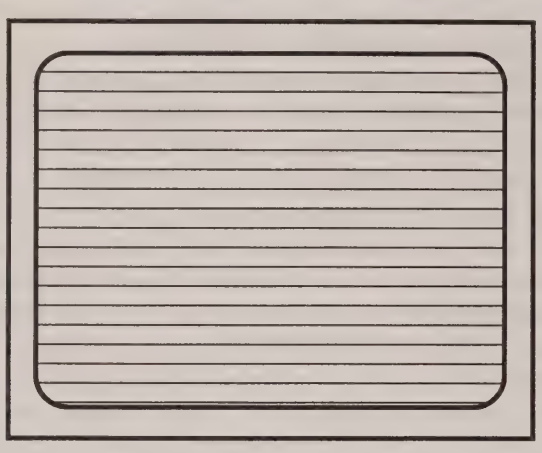
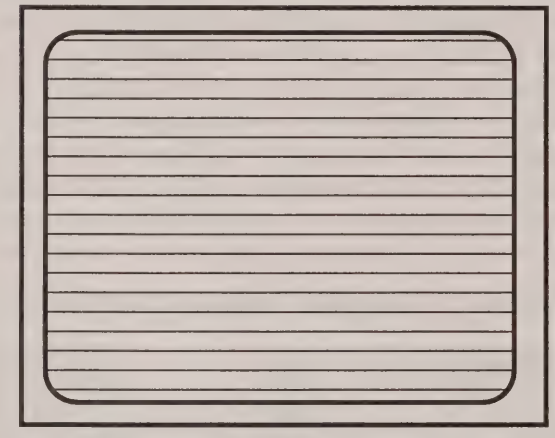


Fig. 3-7. Digital HDTV (left) versus NTSC (right) (Courtesy Zenith.)

Fig.3-8. Video Standards Comparison Chart.



NTSC
Aspect Ratio: 4:3
Field rate: 60 Hz
Number of lines: 525 (483 active)
Method: Chroma color subcarrier at 3.58 MHz
Audio: analog audio



PAL/SECAM
Aspect Ratio: 4:3
Field rate: 50 Hz
Number of lines: 625 (575 active)
Method: PAL color subcarrier of 4.43 MHz; SECAM color subcarriers of 4.40625 and 4.25000 MHz
Audio: analog audio

Grand Alliance HDTV System Parameters
Aspect Ratio: 16:9
Field rate: 24, 30 and 60 Hz supported
Audio: Dolby AC-3 digital audio modulation
Modulation system: 8-VSB (Eight Level-Vestigal Side Band)
Scan Type: Progressive and Interlaced supported
Number of active lines: 720 and 1080 supported
Pixel Arrays: 1280 x 720 lines and 1920 x 1080 lines

systems); Zenith and AT&T (one jointly developed system); and Philips, Thomson and the David Sarnoff Research Center (one jointly developed system). After a review of improvements made to each all-digital HDTV system, ACATS decided that all of these digital systems had provided acceptable results, with no one system so inherently superior to the others that it could be singled out for recommendation to the FCC.

In February of 1993, ACATS adopted a resolution encouraging the above mentioned developers to work together to combine the best features from all the systems into a single HDTV system that is superior to that of any one system developed by the individual proponants. Negotiations ensued between the various system developers. On May 24, 1993, the seven companies annouced the formation of a Digital HDTV Grand Alliance to jointly develop and propose a single, "best of the best" HDTV system as the standard for the next generation of American TV technology.

ACATS subsequently assigned its Technical Subgroup to evaluate the HDTV Grand Alliance's proposed subsystems in detail. The Technical Subgroup approved most of the key system elements—including the use of video compression, the transport and scanning formats, and the audio subsystem—in October of 1993, and the final element, the transmission modulation subsystem in February of 1994.

Key Grand Alliance System Elements

Pixels, Lines and Aspect Ratio. The Grand Alliance HDTV system supports two fundamental arrays of picture elements or pixels: 1920 x 1080 (the number of active pixels per line by the number of active lines) and 1280 x 720. Each of these pixel formats has a widescreen, 16:9 aspect ratio and provides square pixels important for computer interoperability.

Frame Rates. Frame rates of 60, 30 and 24 Hertz (or frames per second) are supported, yielding a total of six different possible scanning formats—two different pixel arrays, each having three frame rates. The 60, and 30 Hertz frame rates are for video source material, while 24 and 30 Hz are important for film.

Progressive Scanning. Another key feature of the Grand Alliance system is the use of "progressive" scanning, which is widely used by today's computer displays. With progressive scanning—also known as non-interlaced or sequential scanning—each line within a video image is transmitted in sequence until the entire image or "frame" has been traced onto the TV screen. The fifty year old NTSC television system, however, is based on what is known as "interlace" scanning. In interlaced systems, the odd numbered lines are transmitted in the first video "field" and the even numbered lines are subsequently transmitted in a second video field. The picture or frame, which is an inter-

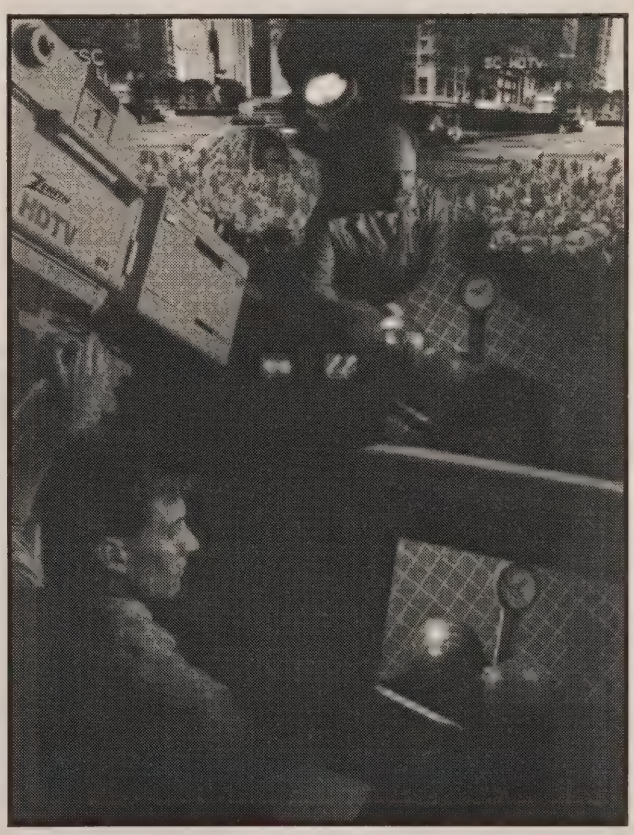


Fig. 3-9. Researchers in Zenith's Glenview, Illinois laboratories evaluate the high-definition picture performance of digital HDTV technology developed by Zenith and AT&T, two members of the Grand Alliance developing the new U.S. HDTV broadcast standard. Foreground: live, digital HDTV image from a special HDTV camera displayed on a high definition monitor. Background: computer-simulated TV images, today's TV (left) and HDTV (right). (Courtesy Zenith.)

laced composite of these two separate fields, is perceived as a whole image by the viewer because of the high speed at which the two fields are transmitted.

Because interlaced pictures display only 30 frames per second, both NTSC and HDTV systems using interlace scanning are subject to flicker when material with sharp horizontal edges is displayed. Progressive scanning brings the viewer a completely new picture twice as fast as the interlaced system. This translates into better resolution and eliminates motion artifacts that can plague interlace systems.

Progressive scanning will be used in five of the six video formats available in the overall system design: all three 720-line formats and in the 30 and 24 Hz 1080 line formats. The sixth format available under the proposed system is an interlaced 60 Hz, 1080 line format important to some broadcasters to assure a smooth transition to HDTV. Although it is neither technically or economically feasible today to provide a 60 Hz, 1080 line progressive scan format, its achievement is a longer-term goal of the Grand Alliance.

Video Compression Format. The Grand Alliance system will utilize the MPEG-2 (Moving Picture Experts Group) international standard for video compression. This use of MPEG-2 will allow HDTV receivers to interoperate with MPEG-2 and MPEG-1 computer and multimedia applications.

Modulation Technique. The Eight-level vestigal sideband (8-VSB) modulation technique developed by Zenith has been selected by the HDTV Grand Alliance because laboratory and field tests have demonstrated that 8-VSB would best provide for the maximum possible terrestrial coverage area for HDTV broadcasts. Other advantages of 8-VSB include the generation of minimal interference to existing analog TV signals occupying adjacent TV channels, and the general robustness of the HDTV digital signal. This technique currently is being refined further to accommodate Grand Alliance MPEG-2 data packets and to include some technical components from General Instrument's QAM adaptive equalization modulation format.

Other Key Elements. Other key elements

Fig. 3-10. A technician from the digital HDTV Grand Alliance adjusts transmitter power in preparation for the start of digital HDTV technology field testing in Charlotte, North Carolina. An integral part of the FCC's standard-setting process, field testing of the Grand Alliance's VSB (vestigal sideband) modulation subsystem began in April of 1994. Charlotte also will be the site of another round of field testing, of the fully integrated Grand Alliance HDTV system, planned for early 1995 after laboratory testing. (Courtesy of the HDTV Grand Alliance.)

include: a packetized data transport—also based on MPEG-2—which will provide the flexible transmission of virtually any combination of video, audio and data information; and compact disc-quality digital audio in the 5.1 channel Dolby AC-3 surround sound system.

Interoperability Benefits

The Grand Alliance's HDTV system has been developed with an eye toward achieving maximum interoperability between diverse entertainment TV, computer and telecommunications technologies so that HDTV can serve as a high-resolution screen for displaying the flow of various forms of digital information into the home. The system features a layered digital system architecture that is compatible with the Open Systems Interconnect (OSI) model of data communications that forms the basis of virtually all modern digital systems (See Chapter 5). This compatibility allows the Grand Alliance system to interface with other systems at any layer, and means that many different applications—including a multitude of entertainment, education and information services—will be able to make full use of various layers of the HDTV system's architecture. Each individual layer of the system is designed to be interoperable with other systems at corresponding levels.

The Move Towards Final FCC Approval

At the time of writing, the Grand Alliance members were working together to construct and test the required hardware for their system. The transmission subsystem was successfully field tested in Charlotte, North Carolina in the Spring and Summer of 1994. ACATS intends to conduct extensive laboratory testing of the final system components in the U.S. and Canada in Winter 1994-95 to verify that the proposed Grand Alliance subsystems meet its expectations. Satisfactory results from this next round of testing will lead to the system's recommendation to the FCC as well as final field test verification of system performance. Completion of these steps ultimately will lead to an FCC rulemaking proceeding which would likely be concluded in 1995. In accordance with FCC requirements, the technology will then be licensed to anyone on reasonable terms.

Playing the Satellite Card

The first appearance of HDTV programming will likely come from satellite-delivered movie services. Movies represent a visual entertainment resource that could greatly benefit from conversion to an HDTV videotape format. Unlike broadcasters, who would have to totally outfit their TV production facilities with expensive HDTV cameras, monitors, recorders, editors and transmission equipment, satellite-delivered movie service providers would only need to have the films converted from 35 millimeter film to HDTV videotape.

DBS operators such as DirecTv and USSB intend to take advantage of HDTV as a drawing card to capture the attention of American TV viewers. In the beginning, however, HDTV satellite broadcasts will largely be limited to movies and special pay-per-view (PPV) events. But by the year 2000, HDTV should make TV viewing a whole new ball game.

The major broadcast networks probably will concentrate their initial HDTV programming efforts on feature films, made for TV movies and sporting events. Only when their affiliates begin to launch new HDTV channels in the major markets will the networks begin offering their entire prime time lineups in HDTV.

Digital TV's Impact on Satellite Capacity

The recent revolution caused by the introduction of digital video compression has caused some concern over its possible impact on the long-term availability and pricing of satellite capacity. Although it is true that demand for satellite capacity will certainly fall dramatically in terms of accommodating conventional NTSC video services, the impending introduction of new digitally compressed video and HDTV services guarantees that there will be fresh demands for satellite capacity in the years ahead. Moreover, satellite programmers will maintain a long simulcasting period, in which analog and digital versions of the various program services will remain accessible.

DIGITAL VIDEO COMRESSION TERMINOLOGY

(from WSTV—European Edition © 1996 MLE INC)

Coping in the new digital age will require a basic understanding of a few new terms which have grown up surrounding this new technology. The following is a brief explanation of some of the new digital jargon which you may encounter.

MPEG. The *Moving Pictures Experts Group (MPEG)* was established by the International Standards Organization (ISO) in 1988 to create a new standard for the compressed representation of multimedia. Finalized in 1991, the *MPEG 1* standard was initially established to handle the compressed digital representation of non-video sources of multimedia such as motion pictures, photos, graphics and text. However, some manufacturers soon discovered that MPEG 1 could be adapted for the transmission of video signals as well. Some TV programmers elected to use MPEG 1 to transmit via satellite while the MPEG committee developed a standard specifcially for video applications known as *MPEG 2*. The MPEG committee finalized its criteria for MPEG 2 in 1994.

Bit Rate. This is the amount of data information being transmitted in one second of time. The total bit stream passing through a single satellite transponder consists of as many as eight TV services with associated audio, auxilary audio services, conditional access data, and auxiliary data services such as teletext. The informational bit rate for this transmission may be as high as 49 Mega (million) bits per second (Mb/s) over a 36-MHz-wide satellite transponder. A single video signal within this bit stream will have a lower bit rate. For example, a VHS quality movie can be transmitted at a bit rate of 1.152 Mb/s; a news or general entertainment TV program at 3.456 Mb/s; live sports at 4.608 Mb/s or studio-quality broadcasts at 8 Mb/s.

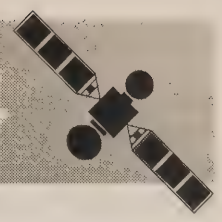
Bit Error Rate (BER). Measured in exponential notation, the *Bit Error Rate (BER)* expresses the performance level of the digital receiver. For example, a higher BER of 5.0×10^{-5} is superior to a lower BER of 9.0×10^{-4}. The higher the BER, the greater the digital IRD's ability to perform well during marginal reception conditions, such as when there is heavy rainfall, snow or wind gusts.

Digital IRD Threshold. Unlike traditional analog IRDs, where the unit continues to deliver a picture even when it is operating below the IRD's threshold rating, digital IRDs stop dead in their tracks when the signal level falls below the digital threshold level of the unit. Its like a light switch: either on or off. Digital IRD manufacturers define the threshold as a BER such as 3.0×10^{-3}. When the BER falls below the IRD threshold, all further reception stops.

Digital Video Broadcasting (DVB). A satellite-specific version of MPEG 2 developed in Europe for DTH TV broadcast applications which numerous satellite programmers worldwide have since adopted for their systems.

Forward Error Correction (FEC). The digital bit stream contains special codes which the IRD can use to check to ensure that all bits of information sent have actually been received. If bit errors due to thermal noise, for example, are detected, the IRD can used the *convolutional encoding* information that has been forwarded to it by the transmitting station to either correct each detected error or conceal it. Other errors caused by what is known as burst noise interference, which can be caused by nearby automobile ignition noise or microwave ovens for example, can be detected by the IRD's *Reed Solomon* block decoder.

Chapter 4



Understanding Digital Video Compression

The long promised "digital information superhighway" is just now beginning to channel a never-ending stream of broadband communications into homes and businesses around the world, with content ranging from video and audio to text and graphics. The driving force behind this revolution is known as digital compression, which transmits telecommunication signals in an abbreviated format that dramatically reduces the amount of frequency bandwidth required without substantially degrading the quality of the received message.

Digital compression techniques already have dramatically altered the way that narrowband communications traffic (such as telephone and facsimile signals) is transmitted within the United States and around the world. Within the past five years, numerous national and international telecommunication service providers have exchanged yesterday's antiquated telephone transmission hardware for new digital telephone equipment that reduces the bandwidth—and consequently the cost—required for establishing a two-way telephone circuit.

The conversion to digital also has dramatically improved the quality of telephone service. Digital signals are not susceptible to the noise problems which commonly degrade the performance of analog communication signals.

Due to the rapid evolution of Integrated Circuit (IC) technology, it now is possible to apply the basic principles of compression to more complex, broadband communications signals such as video. During the past twenty years, the computational power of computers has doubled every eighteen months to two years, while maintaining a cost that is equal to or even less than that of the previous generation. These advances include the development of Very Large Scale Integrated (VLSI) circuit chips. VLSI technology is essential to the complex process of digitizing and compressing video because the amount of information contained in a TV signal is more than 1,200 times the amount of information contained in a conventional telephone conversation.

Digital video compression is making it possible for satellite operators, cable networks and, in future years, even the telephone companies, to transmit multiple TV signals within the amount of frequency spectrum previously used to relay a single standard TV channel. This new technology is fueling a dramatic decline in the operational costs for TV services. The result is an impending explosion in the number of new TV services coming our way, including a plethora of Impulse Pay Per View (IPPV) channels, educational TV services, and numerous narrowcast offerings that target the unique needs of small segments of the general population.

What's more, digitally compressed High Definition Television (HDTV) pictures will be transmitted over the air in the major American TV markets once new HDTV services are introduced later in the decade. Best of all, Direct Broadcast Satellites such as DirecTv's DBS-1 already use digital video compression techniques to transmit more than 100 channels of video through satellite transponders which previously would only have carried sixteen TV signals.

Cable services using satellites for distributing signals to community cable operators also intend to embrace the new compression technology. More than 53 million cable TV households are scheduled to switch to digital cable converter boxes before the end of the decade.

Telephone companies, such as Bell Atlantic, are field-testing compression systems which can transmit video over regular "twisted-pair" telephone lines. Once operational systems are introduced, consumers will be able to retrieve a tremendous variety of stored services through the telephone network. In this sense, we will

become our own TV programmers.

Compression is the key to our evolution from passive to interactive viewers. For example, a subscriber could call and order one of thousands of different movies, previously-aired news broadcasts or sports events, or peruse video catalogs to place orders for various kinds of merchandise. Live broadcasts over the telephone lines also will be possible.

Entertainment television isn't the only area where digital video compression is having an impact. The technology already is playing a major role in the workplace. Moderately-priced desktop videoconferencing systems now make it possible for individuals to participate in important corporate meetings and training seminars without leaving their computer work stations. Multimedia libraries on CD-ROM disc also are available, giving researchers rapid access to a wide variety of video, text, pictures, and other graphic materials. Educational institutions also are finding it cost effective to establish distance learning classrooms which are distributed over wide areas either by satellite or Local Area Networks (LANs).

The Advantages of Digital Compression

Digital video compression offers several distinct advantages over conventional analog transmission systems. Compression can be used in a wide variety of applications irrespective of the transmission medium, whether via cable, fiber-optic or twisted-pair telephone line, MMDS, terrestrial broadcasting, or satellite. Through the conservation of bandwidth, multiple TV signals can occupy the same capacity previously required to transmit a single analog video service. What's more, multiple TV signals sharing transmission capacity easily can be integrated into a package which gives service providers a convenient way to process subscription requests, and deliver TV guides and other programming information. Compression systems even have the flexibility to process a variety of TV source materials, including High Definition TV. Digital video compression also offers program service providers with a high level of encryption security to prevent unauthorized reception.

Compression provides an efficient, even elegant, integration of video, stereo audio, auxiliary audio services, text, and data into a single unified transmission. Moreover, digitally compressed video uses sophisticated error correction techniques to produce pictures free of ghosting, snow and other interference that often plague analog broadcasts.

When used for satellite applications, digital video compression lowers the cost and complexity of networks because less power is required at both satellite uplink and downlink sites. Digital receive-only satellite antennas, therefore, can be less expensive, and much smaller in diameter, than their analog counterparts.

From Analog to Digital Television

In North America, the standard TV signal (NTSC) consists of 525 lines per individual image or "frame." Flashed at a rate of 30 frames per second, each frame has two alternating or "interlaced" fields—each consisting of 262 and

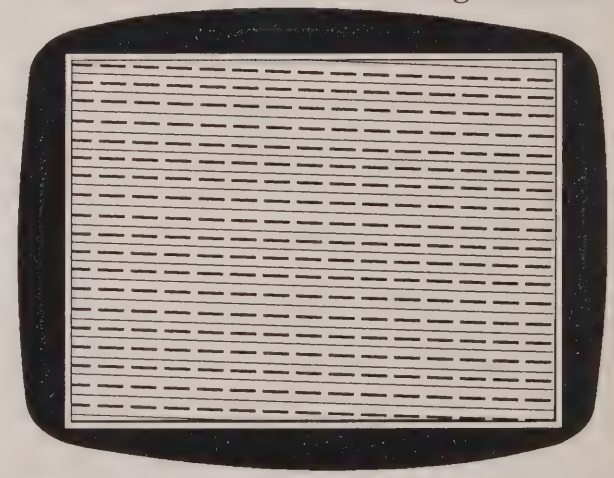


Fig. 4-1. Interlaced scanning. The first field lines (1, 3, 5, ...261.5) are solid; the second field lines (2, 4, 6, ...262.5) are dashes. The two alternating fields are transmitted so rapidly that the eye perceives the image or "frame" as a whole rather than two separate fields.

1/2 lines—with field one consisting of the even numbered lines and field two the odd-numbered lines. The speed at which the fields are transmitted, however, is so rapid that the eye perceives the image or "frame" as a whole rather than two separate components.

In Europe and elsewhere overseas, other

higher resolution video standards (PAL and SECAM) with 625 scanning lines are used, which display images at a rate of 25 frames per second. Like the American system, these other standards use two alternating or "interlaced" fields. All of these systems use subcarriers (albeit with different frequencies for each standard) to transmit the color or "chrominance" information separate from the brightness or "luminance" information carried by the video signal's main carrier.

All of these "analog" TV transmission systems represent visual and audio information as a continually changing wave of energy. Digital TV transmission systems, however, convert the visual and audio information into streams of binary digits or "bits." These bit streams are actually strings of zeros and ones—binary numbers which correspond to the "off" and "on" logic states of computer circuitry.

A single frame of 525-line NTSC video is composed of more than 150,000 picture elements or pixels. Since video operates at a rate of 30 frames per second, more than 4 million pixels are being sent to your TV screen each and every second. A maximum of 32 bits per pixel—8 bits per luminance element and 24 bits per chrominance element—would be needed to digitize a full motion color video image in an uncompressed form. This translates into a transmission rate of 128 Megabits per second (Mb/s), enough to fill an entire satellite transponder to capacity.

Compression Standardization

In 1988, the International Standards Organization (ISO), which operates under the auspices of the International Telecommunication Union, established a technical committee known as the Moving Pictures Experts Group (MPEG) to create an internationally recognised worldwide standard for the compressed representation of multimedia. The committee set out to reach consensus on a compression standard that would allow for maximum flexibility in transmitting and storing multimedia in a digitally compressed form. Another important goal of the committee was to create a relatively simple and inexpensive standard that puts most of the complexity at the encoding end. Representatives from more than 50 companies and organizations from around the world have participated in the MPEG committee's deliberations to date.

MPEG-1

The MPEG initially developed a standard for a wide variety of progressive scan (non-interlace) sources of multimedia, including text, graphics, photos, audio and motion pictures. The model for this MPEG-1 standard was finalized in 1992. MPEG-1 currently is used by CD-ROM computer storage devices which operate at a bit rate of 1.5 Mb/s. MPEG-1 also can accommodate the storage and transmission of video at much higher bit rates. While not initially developed for interlaced video applications, MPEG-1 can process interlaced video by converting it into progressive scanned video at half the normal field rate. Early digital video compression systems developed by Compression Labs (Spectrum Saver) and others have used a modified form of MPEG-1 to inaugurate satellite distribution systems which are serving a variety of business and broadcast customers around the world.

MPEG -2

In 1994, the committee finalized its criteria for the MPEG-2 standard governing interlace scan source material. With MPEG-2, the resolution of compressed video source material has been increased to 704 x 480 pixels per frame (704 x 240 per field) for American NTSC video and 704 x 576 pixels per frame for European PAL video sources. Bitstream rates of up to 40 Mb/s also are possible, fast enough to accommodate a high definition TV signal.

Inside MPEG-2

MPEG-2 compression dramatically reduces the number of bits per second which actually need to be transmitted. This is accomplished in four ways: through pre-processing, temporal prediction, motion compensation, and coding.

Pre-processing. Through preprocessing, information from the video signal which is not

essential to human visual perception is filtered out. Early studies of human perception have been used to establish criteria as to how the individual components of an image must be transmitted in order to maintain fidelity with the original image. Preprocessing removes information from the video signal that is difficult to encode but not very essential to human visual perception. For example, lower frequency visual information is more perceptible to the human eye and therefore is more critical than the higher frequency information. Therefore, the assignment of bits can be prioritized at any given moment according to which blocks need them the most to maintain the maximum perceptible image fidelity.

Motion Compensation. Video sequences are most often highly correlated in time, with each frame in a sequence quite similar to both the preceding and following frames. It is therefore unnecessary to resend those portions of the image in which no elements have changed.

In the MPEG system, the basic unit used for motion compensated prediction is called a "macroblock," which consists of four 8 x 8 blocks of pixels containing the luminance data, and the two 8 x 8 blocks of chrominance data which correspond to the same location in the image as the four luminance sub-blocks. The encoder economizes on bandwidth by instructing the receiver to recall a previous frame's unchanged macroblocks from a buffer storage circuit and reinsert them into one or more subsequent frames. This requires substantially less information, or bandwidth, than sending all frames in their entirety.

"Motion compensation" is used to compute the direction and speed of moving objects within the video image. All macroblocks are scanned to identify those portions which will not change position. "Predictor" blocks also are identified, with their position and direction of motion noted. Only the relatively small difference, called the "motion compensated residual," between each predictor block and the affected current block is sent to the receiver.

If all of these differences are communicated directly to the receiver, no distortions or "artifacts" will be introduced in the displayed image. Artifacts will be introduced whenever there is an insufficient amount of bits available at any given moment to communicate all of the essential image detail and/or rapid motion changes from one frame to the next. In this case, a tradeoff is made between the available bit rate and image fidelity.

MPEG accurately predicts where moving objects should appear in succeeding frames using a very small number of bits. Moving, yet relatively unchanging objects, such as a vehicle or people, are reduced to a mathematical short-

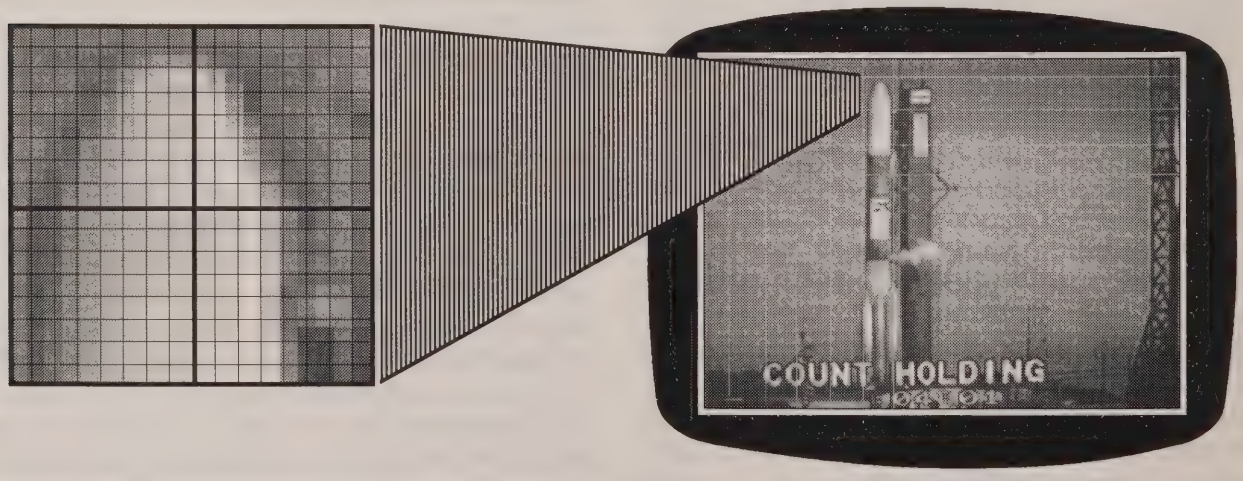


Fig. 4-2. The TV image is subdivided into macroblocks consisting of four 8 x 8 blocks of pixels containing the luminance data, and the two 8 x 8 blocks of chrominance data which correspond to the same location in the image as the four luminance sub-blocks.

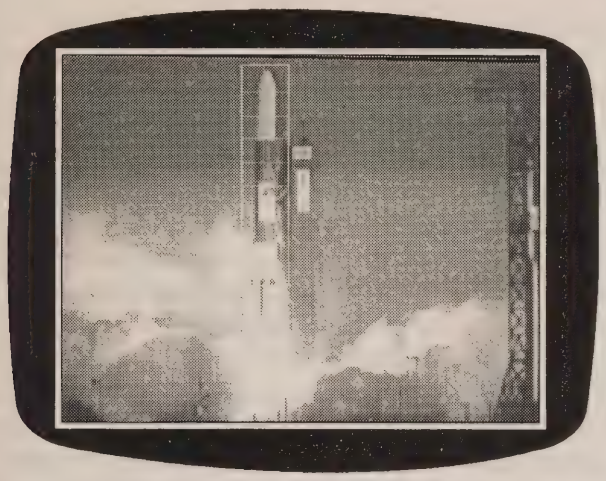


Fig. 4-3a. Predictor blocks are selected which can be converted into a coded short-hand form. Their position and direction of motion also are noted.

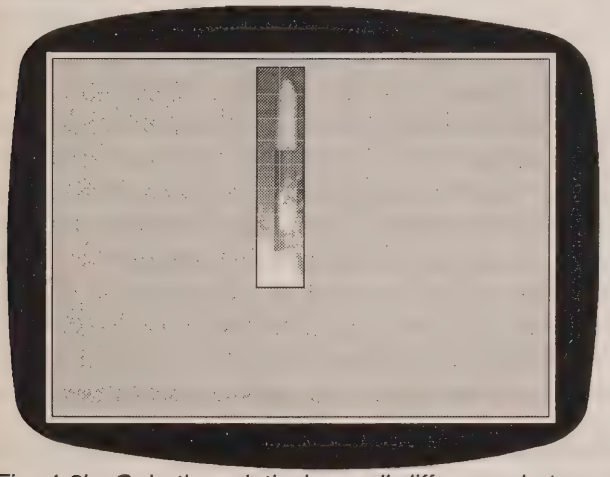


Fig. 4-3b. Only the relatively small difference between each predictor block and the affected current block is sent to the decoder.

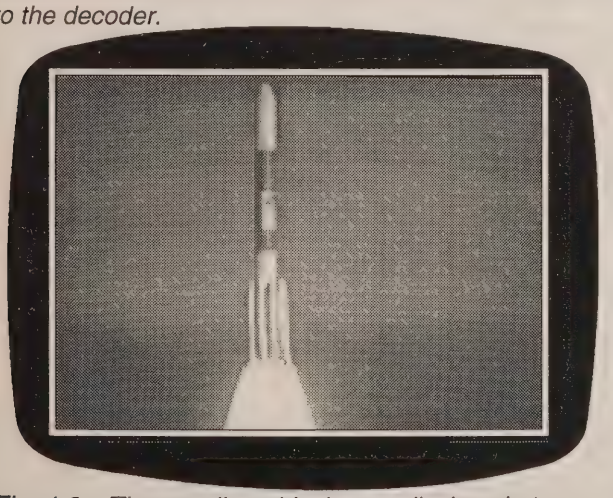


Fig. 4-3c. The predictor blocks are displayed at a new location with a new background.

hand equivalent of "take the same object from the initial frame and move it three macroblocks to screen right for the next frame." Objects which change shape and move at the same time, or multiple objects which are moving in different directions at different rates, do not compress as easily, and therefore require a larger assignment of capacity in the bitstream at any given point. Whenever major scene changes occur, the encoder must transmit an entire set of new blocks and instruct the receiver to dump all of the blocks comprising the previous frame which had been stored in a memory circuit called a "frame buffer."

Discrete Cosine Transform. The frame being coded is predicted from previously coded frames, and the difference between frames is transformed using a mathematical "algorithm" called the Discrete Cosine Transform (DCT). The DCT can reorganize digital blocks of pixels into an even more compact form. Each macroblock is first divided into four "sub-blocks" of 8 x 8 pixels for spatial compression within individual frames. The DCT algorithm converts these sub-blocks from a spatial domain into an equivalent series of numbers in a frequency domain that can be more quickly transmitted.

Instead of viewing the picture information as a block of 64 discrete values arranged in an 8 x 8 matrix, the DCT views it as a varying signal that can be approximated by a collection of 64 cosine functions with appropriate amplitudes.

4 x 4 Motion Compensation Residual					Discrete Cosine Transform Coefficients			
22	24	27	28		106.7500	-10.0604	-0.2500	8.8566
23	24	28	29	=	-4.7877	0.4268	-0.3266	-0.1652
24	25	29	30		0.7500	-0.0560	-0.2500	-0.6533
25	27	30	32		7.5193	0.5901	-0.1353	0.7647

Fig. 4-4. A 4 x 4 block of motion compensation residual (typically 8 x 8 or 16 x 16 pixels) is converted by the Discrete Cosine Transform (DCT) to a corresponding set of coefficients representing different frequency components. Note that the relatively flat input block produces a transform block with most energy in the upper left hand corner. Most of the lower right hand corner coefficients can be set to zero with little effect on picture quality. (Courtesy CLI).

Each cosine value is associated with a DCT coefficient, which represents a different frequency component.

Quantization. The resulting DCT coefficients are quantized according to a perceptual model and the bandwidth available for transmission. Quantization converts the sets of frequency coefficients into more compact representative numbers which take less bits to send. The encoder accomplishes this by searching an internal codebook—a collection or index of possible representative numbers—and then selecting the codeword that best matches the original set of frequency coefficients. Quantization approximates or distorts the original image, but in a subjectively acceptable way, rounding off all values, within a certain range of limits, to the same value.

Huffman Coding. In 1950, Dr. David Huffman developed a unique coding system for compression while studying at MIT. Through Huffman Coding, relatively probable messages are assigned short numerical sequences while relatively improbable messages are assigned long numerical sequences, resulting in a data compression factor of 2.

In an a recent article by E. Sapwater in *PHOTO>Electronic Imaging* magazine, Dr. Huffman gave the following explanation of his breakthrough:

"The coding is often compared to Morse Code, which effectively represents alphabetic and related symbols by signals of varying lengths. The key is to use shorter codes for the things that are more likely to happen. The shortest code in the Morse system is a single dot, which represents the letter "E"—the most frequently used letter in most text. Longer combinations of symbols, dots, and dashes, are for letters like Q, Z, and X that are not used as frequently. Therefore the idea of variable length coding had been around for a long time. Essentially, I was given this concept and asked to provide the best variable length code to work under very general circumstances."

I, P, and B Frames

MPEG provides three types of video frames which can be coded into a digital bitstream. The first frame in any video segment is called an intraframe, or "I" frame. The "I" frame is coded using only information presented within itself—no reference is made to other frames within the digital bitstream. "I" frames occur on an average of one out of every ten to fifteen frames, or whenever there is a scene change. The MPEG algorithm uses the "I" frames as a reference for predicting subsequent frames.

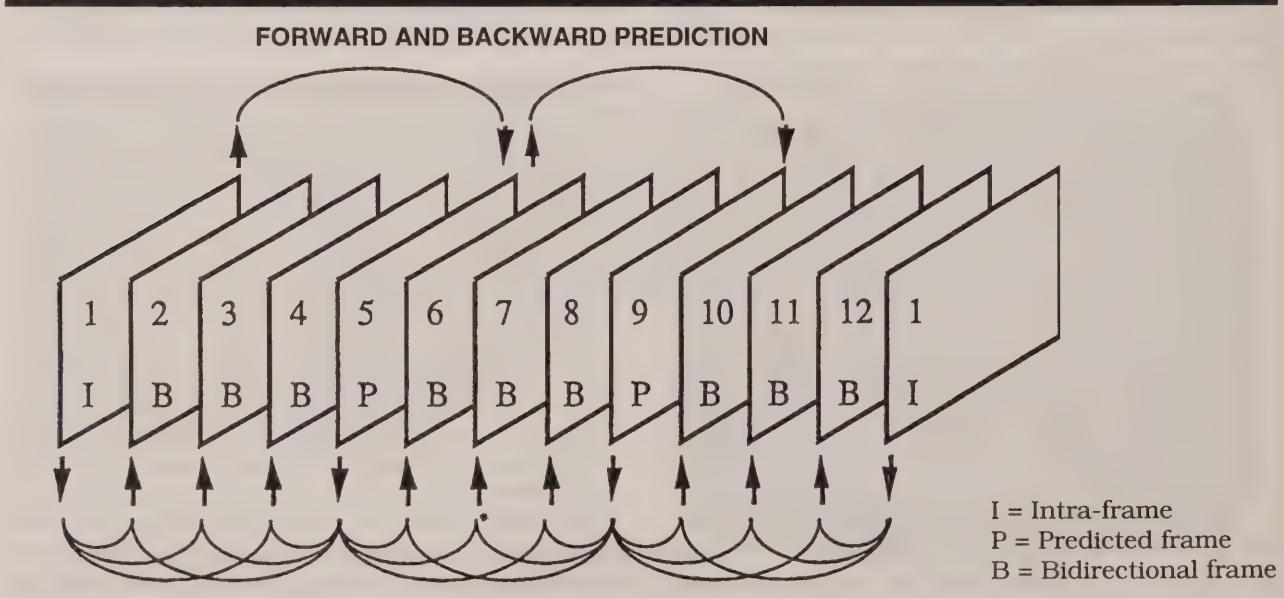

FORWARD AND BACKWARD PREDICTION
1 2 3 4 5 6 7 8 9 10 11 12 1
I B B B P B B B P B B B I
I = Intra-frame
P = Predicted frame
B = Bidirectional frame

Fig. 4-5. MPEG digital video compression using B Frames. (Courtesy of TV/COM International.)

"P" Frames are predicted frames with reference to information presented in the nearest preceeding "I" or "P" frame. These "P" frames also serve as a reference for future "P" frames.

"B" frames are bi-directional frames that are coded using motion-compensated prediction from the nearest preceding "I" or "P" frame *and* the nearest following "I" or "P" frame. The sum of the bits assigned to the "I," "P" and "B" frames cannot exceed the allocated transmission speed (example 6 Mb/s) in any given second.

"B" frames are not used by all MPEG-2 systems. MPEG-2 systems using "B" frames realize a more efficient level of compression—up to 15 to 20 percent—thus needing to transmit less data to achieve the same video quality. The use of "B" frames, however, requires an additional memory buffer for the future reference picture which increases the cost of the decoder.

In order to support the use of "B" frames, the encoder does not transmit the frames in display order to the decoder. Instead, the encoder holds many frames in its buffer, figures out the best pictures to use for "I" and "P" frames and then codes them out of order.

MPEG Data Rates

Real-Time encoders have a finite time to make encoding decisions and thus must make some compromises, either more picture artifacts or a higher data rate for the same picture quality. Non-real-time encoders for movies and other taped material do not suffer from these time constraints because the encoder can slow down and take its time when processing the image to select the best possible method of encoding. This results in a lower data rate for the same quality picture. Live sports and other live action material also require a higher data rate because it takes more bits per second to transmit complex, rapid motion changes without introducing high levels of distortion.

Fig. 4-6. Representative MPEG-2 Data Rates

Service Description	**Data Rate**
Video Services	
PPV Movies (VHS quality)	1.152 Mb/s
News/Entertainment	3.456 Mb/s
Live Sports Event	4.608 Mb/s
16:9 Wide Screen TV	5.760 Mb/s
Studio Quality Broadcast TV	8.064 Mb/s
High Definition Television	14.00 Mb/s
Audio Services	
Monaural sound	0.128 Mb/s
Stereo sound (L + R)	0.512 Mb/s
Digital Data	9.6 kb/s

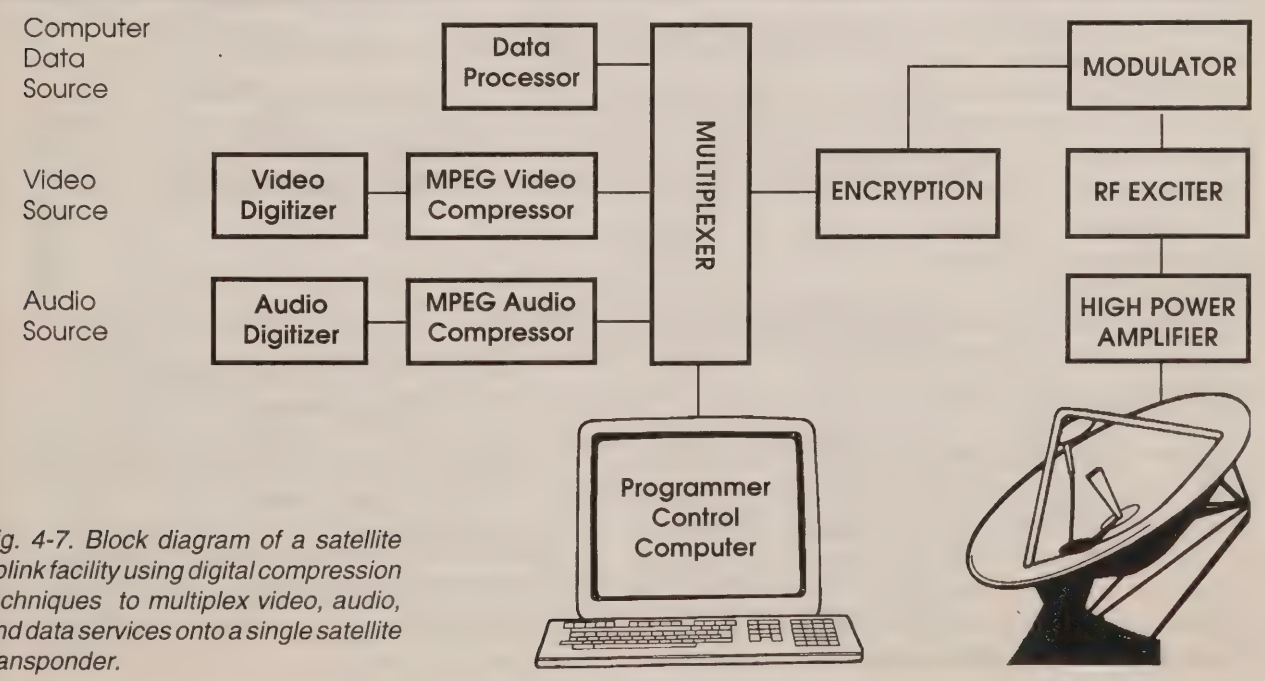


Fig. 4-7. Block diagram of a satellite uplink facility using digital compression techniques to multiplex video, audio, and data services onto a single satellite transponder.

MPEG Compatibility

Numerous digital video compression systems are under development by manufacturers such as General Instrument, TV/COM International, Thomson Consumer Electronics, Compression Labs, and Scientific Atlanta. While all of these manufacturers are basing their systems on the same MPEG-2 standard, compatibility between these various systems will unfortunately be severely limited. The MPEG standard should be regarded as a framework for designers rather than a specific blueprint. It does not define how the encoding decisions are to be accomplished.

MPEG specifies what an MPEG-compliant bitstream must look like. The various manufacturers have leeway in prioritizing the design of their systems according to various criteria such as picture quality versus transmission rate, live versus tape conversion, and cost of manufacture. Differences between various selected methods of encryption used by the manufacturers also act to keep MPEG-2 from becoming a true universal standard.

Interoperability is one major benefit derived from MPEG-2 compatibility. The exchange of program materials on a worldwide basis will become a non-issue for broadcasters who in the past have had to contend with issues involing the standards conversion of video.

Now programmers will be able to MPEG compress their program material so that it can be stored, transported, and reused by any MPEG-2 based system without further conversion. What's more, the major similarities between MPEG-1 and MPEG-2 will allow programmers to transmit previously-compressed MPEG-1 program material through MPEG-2 compliant systems without further need for conversion. The video quality, however, will vary according to the quality of the technology used to compress the programming.

Open Systems Interconnection Model

The International Standards Organization (ISO) has established the following Open Systems Interconnection (OSI) Model in order to foster universal compatibility between various communications networks. The OSI model, a framework for defining the communications process between systems, has been adopted as the framework for MPEG.

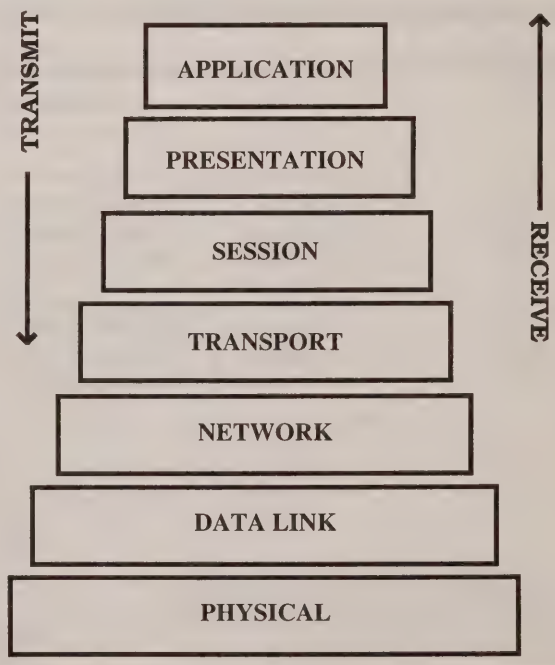
The OSI model defines the functions, services, and protocols involved in the communication process. The seven layers of the OSI model includes the application, presentation, session, transport, network, data link, and physical layers. Each message relayed through a communications system using the OSI model passes downward (transmission) or upward (reception) through each of the model's layers, with each layer aiding and contributing to the communication process.

Application. Serves as the link between communication and application (outside world).

Presentation. Ensures that the message is delivered in a form that the receiving system can understand and access. MPEG features flexible conversion of various video formats: PAL, NTSC, 16:9 wide screen, HDTV, RGB, etc.

Session. Management of message assembly, buffering, and information exchange. In the case of MPEG, provides for the flexible integration of video (interframe and intraframe), audio,

Fig. 4-8. MPEG uses the the Open Systems Interconnection (OSI) Model as a framework.



text (on-screen displays), voice, and data.

Transport. Controls the end-to-end delivery of data—including the multiplexing of multiple messages—and specifies protocols, including error detection and recovery. Governs the interoperability with cable, broadcast, and satellite transmission standards.

Network. Routes communications through network resources.

Data Link. Formats and synchronizes the message. Includes error control and protocols which break up the data bitstream into sequential frames.

Physical. Acts as the interface to the transmission medium. It includes mechanical and electrical interconnections and interfaces.

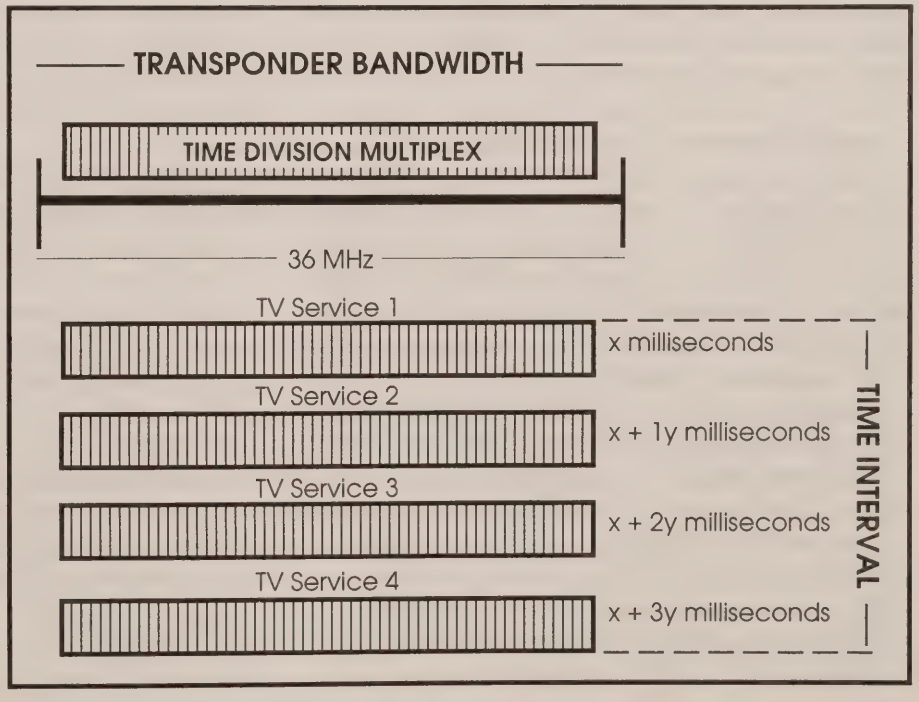
MPEG Satellite Applications

Two different transmission modes are used to deliver MPEG-compressed programming via satellite. *Single Channel Per Carrier (SCPC)* signals have their own independent carriers and frequency assignments within the bandwidth of a given satellite transponder. The main advantage of using SCPC for MPEG transmissions is that programmers at different physical locations can uplink their own MPEG compressed programming and share the same transponder. SCPC commonly is used for MPEG compressed program exchanges, satellite news gathering applications, business and educational networks, or any other part-time service which does not need dedicated 24-hour service.

Multiple Channel Per Carrier (MCPC) transmissions contain two or more program services which are multiplexed into a single unified signal. MCPC affords the advantage that a package of program services can use the same conditional access and forward error correction systems. This economizes on the overall bandwidth and transmission speed requirements.

What's more, programmers can dynamically assign capacity within the multiplex at any given time. A programmer could therefore assign more bits to a live sports broadcast and less bits to a "talking head" infomercial. At the conclusion of the sports event, excess bits could then be reassigned to another service within the multiplex. Or, if a pay-per-view program generates an unusually high number of orders, then bits can be reallocated for decoder authorization to minimize the time be-

Fig. 4-9. Five digitally compressed TV channels transmitted in an MULTIPLE CHANNEL PER CARRIER (MCPC) format sharing the entire transponder bandwidth, with each service assigned its own time slot for transmission.



A 21.5 Mb/s Multiplex can include:
- 2 to 10 standard video services or 1 HDTV signal
- Up to 20 audio channels
- Text at 45 pp per second
- Up to five 19.2 kb/s data channels or 10 data channels at 9.6 kb/s
- And conditional access add-ressing to millions of decoders per hour.

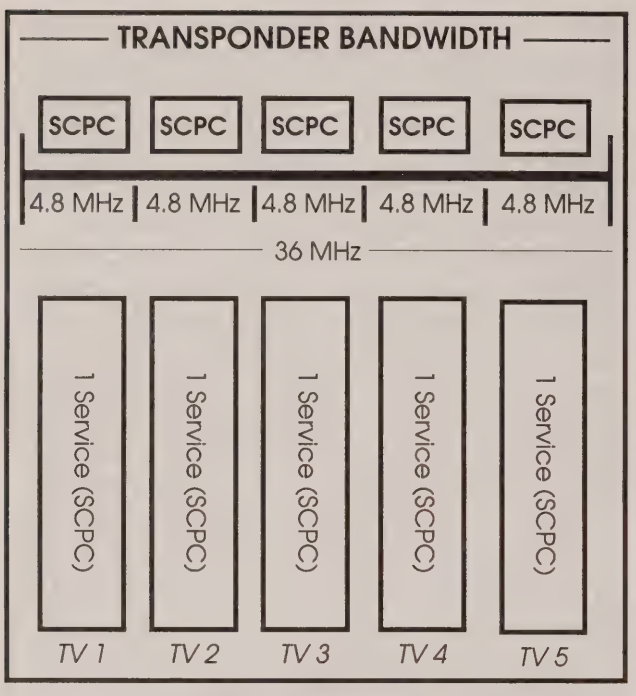


Fig. 4-10. Five digitally compressed TV channels transmitted in a SINGLE CHANNEL PER CARRIER (SCPC) format sharing the same satellite transponder BY assigning different frequency segments for each service.

tween the customer placing an order for a program and their decoder being turned on. The main disadvantage of MCPC is that all program services must be uplinked together from the same location.

Digital Satellite TV Installations

The introduction of MPEG-based, direct-to-home satellite TV will require that installers make changes in their procedures. With analog satellite TV, even very weak signals can be detected by viewing a TV monitor connected to the receiver while adjusting the antenna. When receiving a very weak signal, the first evidence of video is the appearance of sync, then black and white pictures, and finally, color. With digital satellite TV weak signals appear to be noise. The receiver will not display any picture at all until sufficient signal is reaching the antenna.

Similarly, when it starts to rain and the digital Ku-band signal begins to fade down, the picture will remain perfect. Then, all of a sudden, the picture will completely dissappear. In this sense digital video reception is like a light switch, either on or off. Installers of digital satellite TV systems therefore will have to rely on antenna tuning meters or portable spectrum analysers to peak antenna performance.

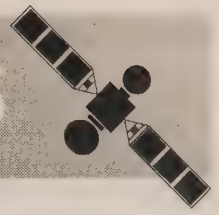
Encryption & Digital Video Compression

Satellite programmers the world over are converting their TV networks from analog to digital. The conversion from an analog to a digital realm will provide programmers with the tools to enhance signal security. Once a video signal has been converted into the digital domain, there are many ways that the bit stream can be encoded to prevent unauthorized access.

This on-going migration to the new digital environment has raised some concerns over how complicated it will be for satellite TV viewers, both in the U.S. and abroad, to receive both analog and digitally compressed satellite TV program services. General Instrument has announced that the DigiCipher II multi-channel digital television system to be introduced in the Summer of 1995 will include a new generation of commercial and consumer IRDs which will be capable of decoding both digitally compressed DigiCipher II and encrypted analog VCRS (VideoCipher Renewable Security) signals.

The new DigiCipher II IRDs also will be able to receive satellite TV programs which are broadcast in the clear. This compatiblity between today's analog world and the new wave of digitally compressed video delivery systems will give new IRD purchasers access to VCRS and DigiCipher II encrypted program services without the need for additional IRDs or stand-alone decoders. This compatibility should ensure a smooth transition as consumers upgrade their present day systems to receive a new generation of program services using digital video compression technology.

Chapter 5



World Video Encryption Systems

Satellite Channel Encryption in Asia & the Pacific Rim

Encryption is an electronic method of securing the video and audio portions of any TV program so that satellite, cable, and broadcast TV services can maintain control over the distribution of their signals. To receive encrypted or "scrambled" TV services, cable and SMATV system operators, hotel chains, private satellite networks and home dish owners must employ a device called a descrambler to sense the presence of an encrypted TV signal and then automatically decode the picture and sound.

Premium program services purchase the rights to movies from film production companies with the understanding that every individual will pay for the right to view them. Programmers are also very concerned about theft of their signals by hotels, bars, and other commercial establishments who derive monetary benefit from their piracy.

Scrambling protects local cable and DTH operators from losing potential customers who might otherwise purchase a dish in order to avoid paying monthly subscription fees. Private business networks also must scramble their signals to ensure the confidentiality of information that is transmitted via satellite to corporate members attending videoconferences or other non-public meetings.

Within a particular region, program producers may license their programs to more than one broadcast outlet. The program producer may require that broadcaster encrypt its signals whenever the broadcaster airs the producer's copyrighted material. This strictly limits reception of the programming to the market for which each broadcaster is licensed. Satellite TV viewers often will encounter this phenomenon the on Palapa C1 satellite. Broadcasters such as RTM-1 and RTM-3 (Malaysia), GMA (Philippines) and Indosiar (Indonesia) periodically will switch from a free-to-air to an encrypted transmission mode whenever required under their respective agreements with the program copyright owners.

How Encryption Works

All encryption or "scrambling" systems have three main components: the encoder, a computerized authorization center, and a network of descramblers. The encoder converts standard TV signals into separate scrambled video and digitally-encrypted audio components.

The authorization center uses a computer to control all descramblers in the system. Each integrated receiver/descrambler (IRD) is assigned a unique address code. The authorization center uses this code to turn individual decoders on or off and even selectively control large groups of decoders. Regional sports networks, for example, use selective group control to "black out" specific programs for those regions of the country where the programmer does not own the rights to the material being aired. Private business networks may also use "tiering" to control the distribution of information within a corporation or among a group of corporations all sharing the same satellite capacity.

Inside The Video Waveform

PAL television cameras divide each televised scene into 625 horizontal lines. Any one line is made up of a number of dots called pixels. Each pixel is assigned a distinct level of luminance (brightness) and chrominance (color).

Every televised scene or "frame" of video is transmitted in two alternating fields of 312.5 horizontal lines. These "interlaced" fields are scanned at a rate of 50 times per second. The rate of change happens so fast—more than 31,000 lines are being scanned each and every second—that the human eye interprets the two

fields as a single picture.

The *horizontal blanking interval* which takes place at the end of each line, contains a *sync pulse*—a kind of control signal that turns off the TV picture tube's electron gun while the beam is repositioned to start the next line. The *vertical blanking interval*, which takes place at the end of each complete field, also contains a sync pulse that commands the electron gun to move back to the top of the screen before scanning the next field of 312.5 lines.

"Soft" Video Encryption Systems

The analog (i.e., non-digital) scrambling systems developed for satellite transmission most often encrypt the video by stripping away the vertical and horizontal sync pulses prior to uplinking the signal. Without these control signals, conventional TV sets are unable to determine just when to begin tracing each new line within a field or when a new field begins. The satellite uplink's encoder also creates a negative image by inverting the video signal. Examples of analog encryption include the E-PAL system used by Indosiar and various Australian broadcasters.

As another security precaution, some analog scrambling systems relocate the chroma color burst signal to a non-standard frequency which only the IRD's descrambler module can detect. A special digital sync pattern transmitted by the uplink also commands the IRD to regenerate the proper horizontal and vertical sync pulses internally, so that the unencrypted video can be displayed on conventional TV screens.

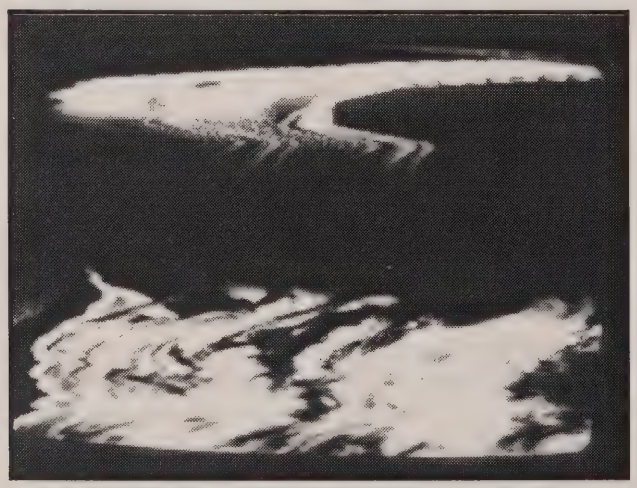


Fig.6-1. A n Encrypted Analog Video Signal.

In some encryption systems, such as the one used by GMA on Palapa C1, an optional *Scene Change Detector* can be used to detect scene changes and alternate the scrambling mode during intervals when the video content changes abruptly. Multiple inversion modes are available, with the video inverted on either a field-by-field or individual line-by-line basis. A random inversion mode also is available, where the video is inverted at non-standard intervals from a positive to a negative image and back again.

Security Features. Every descrambler module is assigned a multi-digit unit address number that has been pre-programmed into its electronic circuitry. This unique address code is displayed on the TV screen whenever the " 'set up' 1" mode (or manufacturer's equivalent) is selected from the IRD's handheld control. Commercial users such as a cable system operator, as well as consumers in the case of DTH systems, must supply the programmer with the unit's address number whenever ordering a scrambled service.

Some video encryption systems also feature a "security smart card" that is about the size of a typical credit card. In the case of a system using a smart card, the IRD's descrambler module will have a corresponding security card reader slot on its chassis. The smart card itself, however, may only be distributed if the encryption system is compromised and programmers elect to migrate to a higher level of security.

The security card consolidates multiple encryption features into a single, high-security electronic "Super Chip" which contains a special set of mathematical algorithms that must reside within a decoder's circuitry before encrypted signals can be unscrambled.

Each encryption system operator is provided with a computer system and software which can only address those decoders assigned to their respective networks. The decoders for other services using a specific system cannot be readily addressed without first obtaining access to the appropriate software.

Signal Authorization. The subscriber's IRD address number is forwarded on to the

programmer's Authorization Access Center. From there, a specific authorization message is sent over the satellite which activates the individual IRD and instructs it to decode the particular service or services. The entire authorization process can be completed in a matter of seconds. The programmer also can remove each IRD's unique authorization message from the data stream at any time. Without the authorization code, the IRD will no longer be able to decode the encrypted signal. Some of the latest encryption system also includes electronic countermeasures that can be used to shut off illegally-modified descramblers if the system ever is compromised in the future.Most encryption systems employ tiers—special encrypted data codes which are allotted to each program provider. Each program provider within a program package is assigned one or more unique tier bits, with each bit capable of authorizing reception of either a single pay TV event or full-time subscription service or an entire package of subscription services.

The "Conditional Access" data is inserted into the vertical blanking interval of the video signal. The more lines allocated to this data stream, the greater the number of decoders which can be addressed in a given authorization period.

During the authorization process, if the program doesn't automatically appear on the screen, the service representative will ask the subscriber to press a 'SETUP' button (or manufacturer equivalent) to display an informational chart—called the Diagnostic Data chart—on the screen of the TV set. The service representative asks the subscriber to read off these 'hidden' codes to determine just why the subscriber is not receiving the transmission.

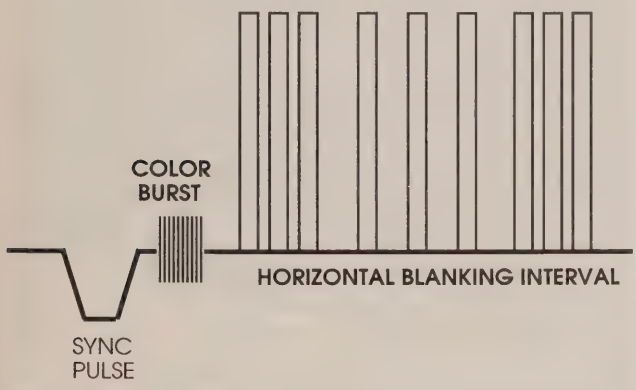


Fig. 6-2. The conditional access (CA) data, which tells the decoder how and when to descramble, is inserted into the vertical blanking interval of the video signal.

Audio Encryption

Many satellite TV encryption systems rely on video encryption as a deterrant to unauthorized reception. The audio portion of the TV program remains accessible to anyone with a satellite TV receiver. Programmers may even prefer to have the audio unencrypted as a way to make satellite TV viewers aware of the potential availability of their services.

Scrambling systems which digitally encrypt the audio signals have been developed for those programmers who may require secure transmission of both the video and audio components of their programming. At the uplink, the audio encoder converts the sound portion of each TV program from an analog to a digital signal expressed as binary numbers which correspond to the "off" (0) and "on" (1) logic states of computer circuits. Audio pitch and intensity are therefore expressed as a stream of binary digits or "bits." While standard analog audio signals are sent in real time, digital signals are sent in bursts of pulses, then stored and released over time to recreate the original sound. The horizontal blanking interval of the video signal transmits the digital audio channels and one or more utility data channels.

This digital audio bit stream is encrypted according to a kind of formula known as an "*algorithm.*" Each digital audio sample is added to a key—a random sequence of binary numbers created by the algorithm. Only those downlinks which possess the correct "key" can translate the binary digits into the original signal.

Digital audio represents the ultimate method for delivering superb sound directly to homes and cable "head end" systems. The conversion of the sound to a digital signal prior to encryption allows satellite system to receive an unparalleled level of fidelity which approaches the dynamic range (S/NR of 90 to 95 dB) achieved by the compact disc player.

Compact discs use a 16-bit pulse code modulation (PCM) source to deliver a theoretical

dynamic range of 98 dB. VCRS uses a 15-bit PCM source code with a theoretical dynamic range of 92 dB. VCRS IRDs achieve a minimum dynamic range of 75 dB, with most achieving an 80 dB dynamic range.

Special "error coding" information also is included in the digital bit stream which allow the IRD to detect and correct errors caused by the introduction of noise during the transmission process. These pulses are sent at a high bit rate in each video line's the horizontal sync pulse. All single-bit errors can be detected and corrected and all double-bit errors concealed. Since only signal is detected, noise is eliminated. In analog systems, the noise is amplified along with the signal. The removal of audio subcarriers from the satellite transmissions also results in more of the transponder's power being supplied to the video signal, thereby significantly improving the overall performance of the receiving system.

Analog audio encryption systems also are available. In this case, the sound information may be superimposed on a low frequency sine wave or the audio spectrum inverted to deprive audio access to conventional satellite TV receivers and IRDs. Audio scrambling, however, h proved to be very popular as most programmers prefer to give unauthorized viewers a "taste" of what they are missing.

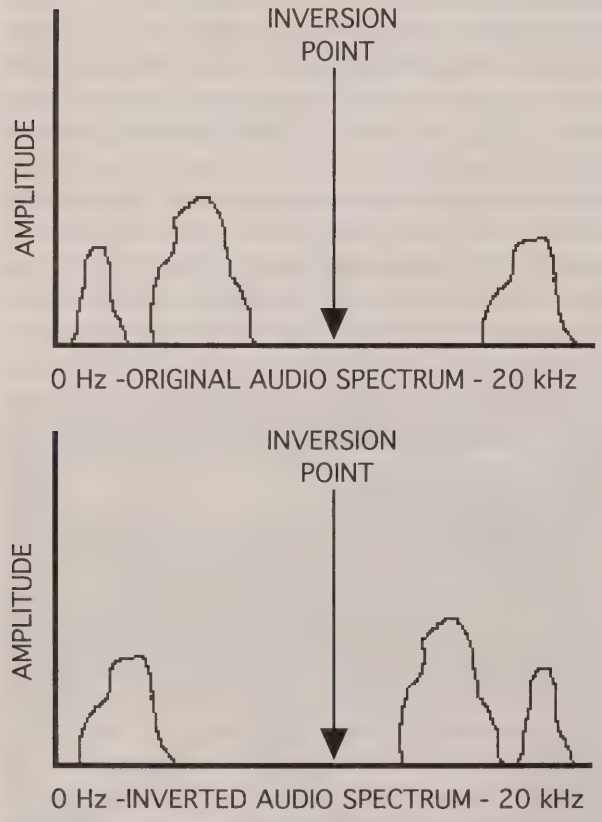


Fig.6-3.With audio spectrum inversion, the audio baseband is reversed, i.e., high frequencies become low frequencies and vice versa.

"Hard" Encryption Systems

Satellite TV broadcasters such as STAR TV (Videocrypt and STARCrypt), TNT/Cartoon Channel (Videocrypt on Apstar 1), RTM-1 and RTM-3 use a "hard" encryption format which digitally encrypts both the video and audio compoenents of the TV signal. Through a process known as line translation, segments of each digitized line of video are sampled by the encoder and converted into digital values. The digitized line segments are then cut and rotated so that the segments within each line are shuffled out of order and reassembled at either side of the cut points. Each line has different cut points; all vertical information in the picture is broken up—stepped back and forth across the screen with each line—and in a sequence that changes from field to field. The audio may also be digitally encrypted if required along the lines previously mentioned in this chapter.

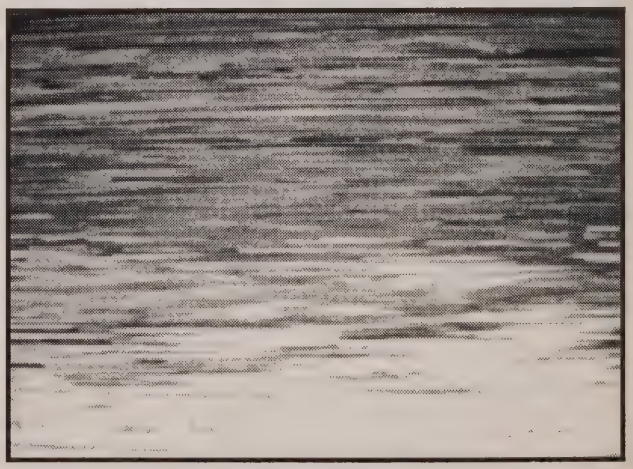
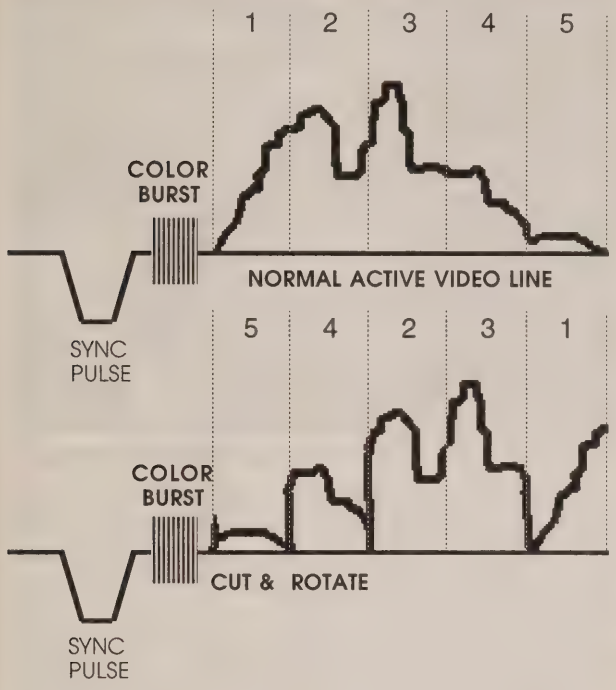


Fig.6-4. Display of aSignal Using the Line Translation Encryption Method..

Fig.6-5.Line Translation Scrambling.



The cut points for each line are chosen at random by a Pseudo Random Binary Sequence (PBRS) generator which is synchronous with both the uplink transmitter encoder and downlink receiver decoder. As the uplink encoder periodically interrupts and restarts the final control algorithm, the encoder must send a special "seed" code to the decoder to tell it just when and where to re-start. This keeps the decoder dynamically locked to the uplink PBRS. New seeds are generated and transmitted periodically to each authorized decoder in the system. This seed, which also is encrypted, is transmitted within the TV signal's vertical blanking interval.

The algorithms needed to unlock the encrypted seeds are either embedded in a tamper-proof medium within each decoder or supplied by the subscriber's security card.. They can be changed at any time to thwart piracy.

The decoder performs the complementary cut-and-rotate operation, patching each line back together at the correct point to reconstruct the original picture. Data for the cut points is derived from data transmitted in the video's vertical blanking interval.

B-MAC

Scientific-Atlanta's B-MAC (Multiple Analog Component, Type B) scrambling system is used by numerous satellite programmers and service providers. Within the Asia-Pacific region, users of B-MAC include HACBSS and RCTS service providers in Australia, the Indovision DTH program package on Palapa C1 (HBO, ESPN, Discovery Channel, and TNT/Cartoon Network) various Apstar 1 program providers using the Apstar 1 satellite (Discovery Channel, Disney Channel, ESPN, and HBO) Channel 9 Australia and Hong Kong/Macau horseracing service providers.

B-MAC encryption offers "hard" video security through a technique known as *line translation scrambling.* Each line of video information is delayed by several microseconds, creating B-

Fig.6-6. Display of a B-MAC Encrypted Signal.

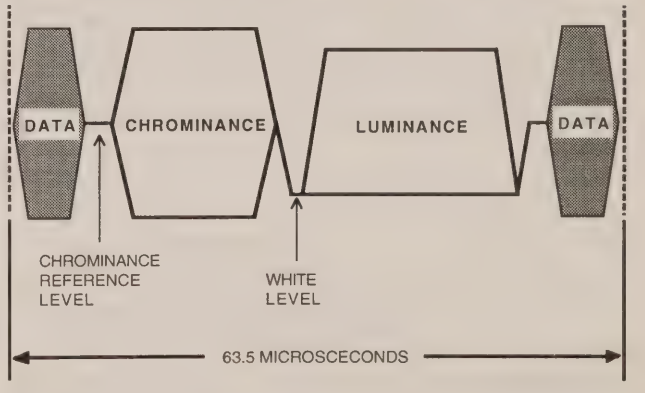


Fig.6-7. MAC sequentially transmits data, chrominance, and luminance within each individual horizontal scan line.

Fig. 6-8. Chrominance & Luminance in a B-MAC signal.

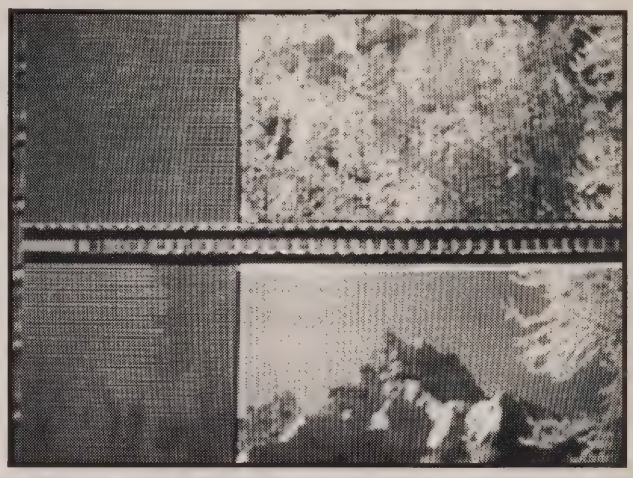


Fig. 6-9. Display of B-MAC Vertical Blanking Interval.

MAC's characteristic diamond-hatched pattern. Only those terminals equipped with decoders that are addressed by a packet of data contained in the vertical blanking interval of the B-MAC signal can descramble the signal. B-MAC's horizontal blanking interval contains up to six digitally-encrypted audio channels and one utility data channel.

While B-MAC does supply customers with relatively-secure and addressable communications signals, it is not just another scrambling system. B-MAC provides the additional benefit of increased signal performance at low carrier-to-noise levels when compared to an NTSC video transmission. B-MAC's improvements over NTSC equates to savings for users, since they can use smaller, less expensive ground stations on the receive portion of the network.

B-MAC sequentially transmits the color information in one-third the active scanning time of each frame and the monochrome information in two-thirds the active scanning time. This prevents the chrominance and luminance signals from interacting with each other, thereby generating unwanted *artifacts* in the video. The video performance is further improved by the use of a digital sync pulse.

By displaying the video's vertical blanking interval, the individual lines which carry various signals can be displayed. Line one transports the digital clock recovery signal, line two carries the digital sync recovery signal, line three sends the system data, lines four through nine handle the address data packets and lines 10 through 15 hold teletext packets. The horizontal blanking interval can contain as many as six 204 kb/s digital audio channels and one 63 kb/s utility data channel.

The digital encryption standard "key" to the line delay pattern for any service can be changed at frequent intervals, precluding a one-time cracking of the code. Only those terminals equipped with B-MAC decoders which are addressed via a packet of data contained in the vertical blanking interval can switch on and decode the signal.

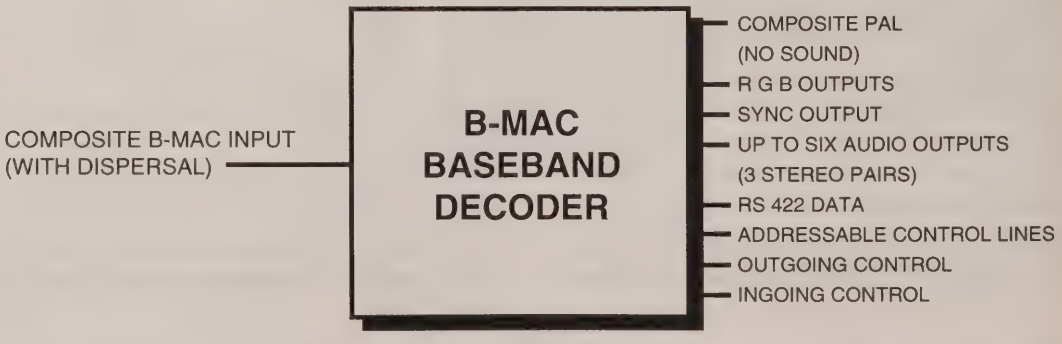


FIG. 5-10. B-MAC BASEBAND DECODER INTERFACES.

Satellite Encryption In Europe & The Middle East

by Stephen J. Birkill

In December of 1975, Stephen J. Birkill became the first private individual in the world to receive satellite TV in his own home. Using a five-foot dish made out of screen and electronic circuitry built on his kitchen table, Stephen received the transmissions of India's Satellite Instructional Television Experiment (SITE), which at the time were being beamed to thousands of Indian villages by NASA's experimental ATS-6 satellite. In the years that followed, Stephen continued to pioneer in the design of satellite receivers and feedhorns. The results of his earliest investigations, which were published in CATJ magazine during the late 1970s and early 1980s, provided valuable guidance to what was then an infant industry. In the mid-1990s, Stephen's satellite tuner designs for Amstrad are in daily use in millions of homes across Europe.

Fig. 5-11. In December of 1975, Stephen J. Birkill became the first private individual to receive satellite TV in his own home. (Photo courtesy of S. J. Birkill.)

Satellite TV transmissions are no respecters of laws, politics, authorities or frontiers. A signal beamed into any part of Europe will be receivable (with a big enough dish) throughout the continent and beyond, by anyone with a satellite receiver. The signal may carry pay-TV material, business teleconferencing, private transmissions for a closed user group, or "free" broadcast programmes whose copyright is restricted to a known audience in a single country. Whether to protect rights, as a means of selling programmes ("subscriber management"), or to ensure the privacy of a network, conditional access systems all have a single aim: to give service providers a measure of control over who watches their programmes.

The level of control can be token, perhaps to satisfy national rules on copyright, advertising or decency, or total, to secure a private network or finance a premium movie channel. A variety of conditional access systems have appeared over the years, with various levels of security and additional features such as individual or group addressability, subscriber messaging, lockout by programme category, impulse pay-per-view and so on.

All of these systems use a form of scrambling, in which the standard picture and/or sound signals are altered before transmission, distorted in such a way that a normal receiver cannot make sense of them—the viewer is presented with a meaningless jumble on the screen and sometimes an unintelligible noise from the loudspeaker. To recover the original information a decoder is required, which is supplied (usually) by the programme provider and authorized only for approved (or paid-up) viewers.

Encryption means the process of scrambling with a hidden cipher key, but the word is used generally to encompass the total system process, including in particular (in the more sophisticated systems) the secure transmission of the necessary entitlement and decoding keys to descramble the signals.

Ideally, all transmissions requiring encryption would share the same scrambling and authorization system and the same underlying signal format, so that a single receiver and decoder could be separately authorized by the

various service providers to give access to their programmes. This is far from the case in Europe today, and things have improved only a little since I described the situation in the 1992 edition of the **World Satellite Almanac**. At the latest count there are seven PAL/SECAM based systems and five different MAC combinations (of which more later) in use for TV distribution or broadcasting on European satellites, plus one all-digital format. Imagine a receiver with thirteen decoder boxes! Even the original "hot bird" Astra constellation has six mutually incompatible encryption systems (plus clear PAL) among its fifty channels.

Scrambling Requirements

Scrambling systems for television distribution must be inexpensive, secure and transparent. Inexpensive so that the cost of coding and decoding for satellite transmission does not render the use of a satellite channel uneconomical. The acceptable cost per decoder depends upon the number of receiving stations in the network. For direct broadcast applications it is essential that the DBS viewer's receiver/decoder combination can be manufactured in high volume at low cost.

The security requirement demands that more than a trivial modification to a standard receiver be required to decode the signal—a special decoder must be used. Ideally the decoders should be difficult to copy, or at least require a component or sub-system carrying a unique decryption key, perhaps a chip or a card, to be intrinsically copy-resistant. There is a wide trade-off range between cost and level of security; the token systems have long been pirated, but many of the more secure are now also crumbling under the assault of more sophisticated hackers.

Transparency means that the signal quality should not be impaired by the encoding and decoding process. In practice any analogue method of scrambling is vulnerable to transmission path distortions, making the scrambled "pieces" not quite fit back together when decoded. The trick is to minimize the visibility of the errors for typical transmission conditions.

Scrambling Methods: PAL and SECAM

The simplest scrambling systems rely upon corrupting the synchronizing pulses which form part of the composite video signal, so that a standard TV set cannot lock its line (horizontal) or field (vertical) timebases. This is known as sync suppression or denial. The picture waveform is transmitted unchanged, but without normal syncs the screen displays only a jumble of picture components. The synchronizing information is transmitted in a disguised form which can be detected by the official decoder and used to reconstruct standard sync pulses.

A further measure of security can be added by inverting (amplitude reversing) the picture signal, either continuously or in a variable alternating sequence switched at line or field (or pseudo-random) rate, or triggered by scene changes. A key to the inversion sequence must be embedded in the signal, in such a way that the decoder can restore normal pictures.

A more complex means of scrambling involves transmitting a normal set of line and field syncs, but modifying the timing of the picture information within that sync framework. This can be done by delaying or advancing the start of picture information on one line relative to the previous line (line translation), by cutting each line's picture information into two parts and transmitting the second part before the first, with a different cut point on successive lines (line segmentation or rotation), or by changing the order in which lines are transmitted within the field (line-shuffling). Or by a combination of these.

Sync Suppression/Inversion Systems

Oak Orion. The first system used by a pan-European satellite service was a PAL version of the USA's Oak Orion, later known as Racal-Oak Nimrod, which Sky Channel used in the early 1980s. This removed the normal sync pulses and substituted bursts of a 2.5 MHz sine wave, which could readily be recovered by the decoder. Various patterns of picture inversion were also available. Additionally the Orion sound channel was transmitted by digitizing the audio signal, scrambling the bit stream and inserting it into the line sync period after the 2.5 MHz

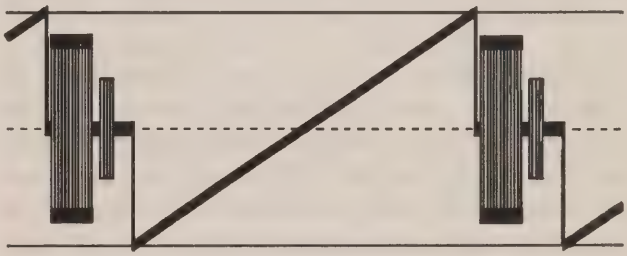
burst. In fact this gave the sound a high degree of security but offered little protection to the vision signal.

The externally imposed requirement to encrypt was at that time an embarrassment to Sky's advertising-supported service, and with the later introduction of a compact non-addressable decoder for DTH (direct-to-home) viewers the channel took the opportunity to transmit its sound channel on a clear subcarrier, removing all obstacles to piracy. Shortly afterwards the channel abandoned scrambling.

With the move to Astra in 1989, Sky Channel evolved into Sky Television (now British Sky Broadcasting) where it turned full circle by introducing the VideoCrypt system to control access to its premium channels.

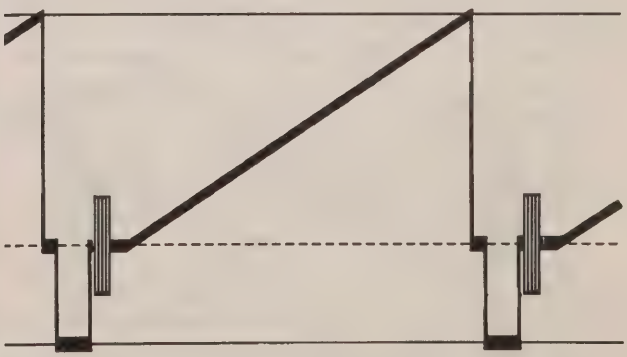
Irdeto. Oak Orion is no longer used in Europe, but the Astra-delivered Luxembourg Dutch channels RTL-4 and RTL-5 scramble some of their programmes using a derivative known as Irdeto, with decoders called Luxcrypt. The same system is used by the African C-Band services of M-Net. Figure 5-12 shows a "pulse-cross" display from a satellite receiver (Chaparral Cheyenne International) which inserts its own sync pulses when standard syncs are not present. The studio's line sync, normally a vertical black bar, is replaced in the encoding process by the digital audio/data signal (the vertical band of "noise"). Coded field sync information can be seen just below the on-screen text, and the horizontal band of dots below that carries the channel's teletext service.

Comparing the simplified Irdeto waveform (Waveform 5-1) with its clear PAL equivalent (Waveform 5-2) shows the data block in the sync period, followed by the PAL-colour burst. Picture information is represented in these diagrams by a line sawtooth waveform, a linear fade from black to white along the line. Irdeto shifts blanking level (the datum level of the sync "back porch" where the colour burst sits) to be equivalent to mid grey picture, further confusing the TV set. At times the active line video is also inverted.



Waveform 5-1. Irdeto/Luxcrypt system shifts blanking level, replaces sync with digital audio and has option for video inversion.

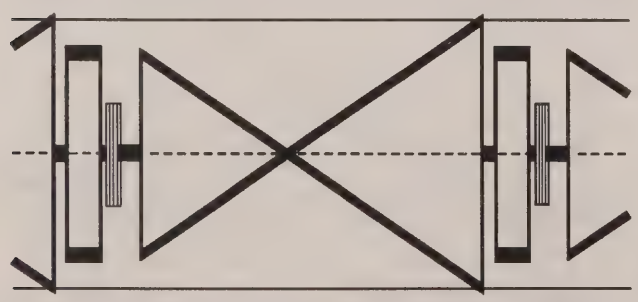
Fig. 5-12. PAL scrambling by Irdeto/Luxcrypt (no inversion), RTL-4, Astra.



Waveform 5-2. Line sawtooth waveform, clear PAL.

Fig. 5-13. Satpak with alternate field inversion (FilmNet, Astra, 1991).

Satpak/Satbox. This system, developed by Matsushita, was employed for some years by the FilmNet pay movie channels (Figure 5-13), on Astra and Eutelsat. Here the sync pulses are retained, but again blanking level is shifted to correspond to mid grey (Waveform 5-3), with the effect that sync pulse edges cannot be separated from picture information. The entire waveform, syncs and all, is inverted on a field-by-field basis, though other sequences (e.g. three fields inverted, one erect) are available. The switch of line sync polarity (immediately after field sync) is clearly visible in Figure 5-13. Satbox decoder synchronizing information is transmitted by subcarrier. The low level of security inherent in the system meant that FilmNet was widely pirated in the early 1990s. The channel has since abandoned Satpak encryption entirely, and uses a combination of VideoCrypt, D2-MAC/Eurocrypt and NTL 2000 digital compression for its FilmNet Plus, Complete Movie Channel and MultiChoice Kaleidoscope services on Astra and Intelsat.



Waveform 5-3. Satpak/Satbox (Matsushita) shifts blanking level and inverts alternate fields.

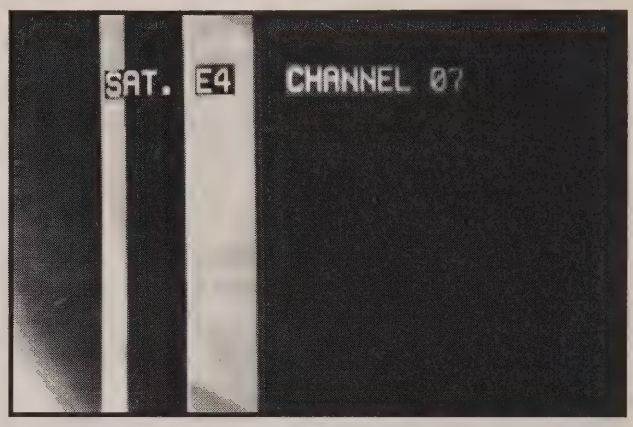
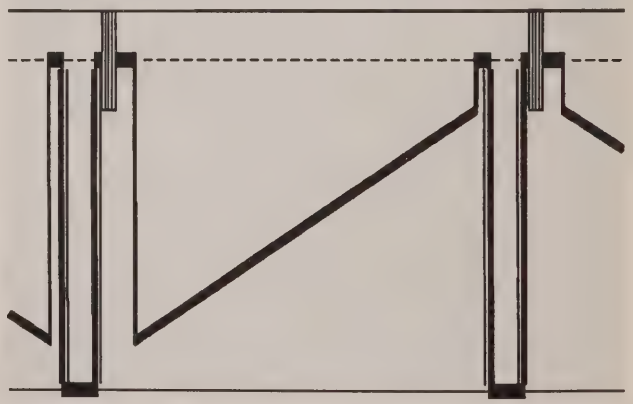


Fig. 5-14. Payview-3 with Alternate Field Inversion (on Teleclub, Astra, 1991).

Payview. Another system now obsolete in Europe, Payview was used by German-language film channel Teleclub, transmitting from Switzerland via Eutelsat during the mid 1980s, and later switching to Astra. Payview again shifts blanking level, but to a value above peak white (Figure 5-14), while holding sync tips below black level (Waveform 5-4). This allows the satellite receiver's (and the TV's) black level clamp to function, effectively blacking out the picture information. The active line (picture) period is inverted on a line-by-line basis, a transparency problem even for the official decoders. As an extra trick, Payview "dithers" the timing of its line sync pulse from one field to the next, causing the TV's display to jitter from side to side. Like SatPak, Payview was extensively



Waveform 5-4. Payview shifts blanking level, dithers sync, and inverts alternate active lines.

Fig. 5-15. Appearance of SAVE-encrypted broadcast.

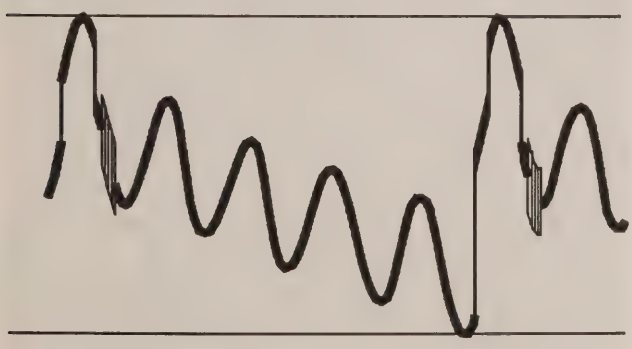
pirated and Teleclub eventually joined other channels of the Canal Plus grouping in a move to the consumer version of Nagravision, the considerably more secure Syster (see below).

SAVE. Satellite Audio and Video Encryption (SAVE) was developed by U.K. company Sat-Tel from the U.S. MAAST system, for use by the early U.K. film channel Prem1ere. Curiously all the British satellite movie channels before Sky Movies (Prem1ere, TEN, Mirrorvision) used either soft scrambling or no scrambling. None has survived, not for that reason but because they targeted U.K. cable TV rather than DTH or DBS, which at that time severely limited their subscriber base.

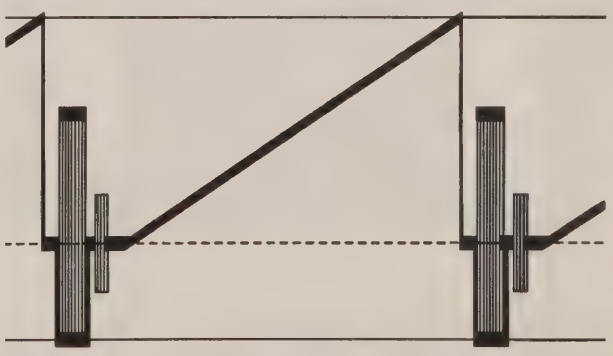
SAVE (Fig. 5-15) was also used for a period by BBC TV Europe, the precursor of BBC World Service TV whose European service now employs D2-MAC/Eurocrypt. In SAVE, the composite video signal is inverted, reduced in level and has additional pre-emphasis applied in an attempt to counter the loss in signal to noise ratio (S/NR). Then a sine-wave interfering signal is added to the video, at a similar amplitude to the sync pulses (Waveform 5-5). This effectively defeats the TV's sync separator, giving an unlocked raster. Unfortunately it proved difficult even for the official decoders to ensure accurate cancellation of the sine wave in amplitude and in phase, and subscribers often had to suffer ripple patterning as well as grainy pictures. The audio part of SAVE is a simple frequency-inversion scrambling, using a conversion frequency derived from the video sine-wave.

Sound-in-Syncs. While not strictly a scrambling system, this method of multiplexing a digital audio signal into the composite waveform does effectively destroy the normal line sync pulse, requiring its own decoder to reconstruct the standard video waveform. The system was designed by the BBC in the late 1960s to provide high quality mono sound-with-vision distribution to its terrestrial transmitters, and has since been adopted by the European Broadcasting Union for the Eurovision network. Four wide beam 72 MHz transponders on Eutelsat II F4 at 7 degrees East Longitude carry a total of six SiS-coded TV channels which are in daily use for news feeds and programme exchanges among EBU members.

Two 10-bit data words are interleaved (but not scrambled) and inserted into the line sync pulse (Waveform 5-6). Otherwise the video signal is unmodified PAL or SECAM, according to source. On occasions the same or an alternative sound channel is transmitted via subcarrier,



Waveform 5-5. SAVE inverts, attenuates, and pre-emphasises video, and adds sine-wave interference.



Waveform 5-6. EBU/BBC sound-in-syncs replaces line sync with digital audio.

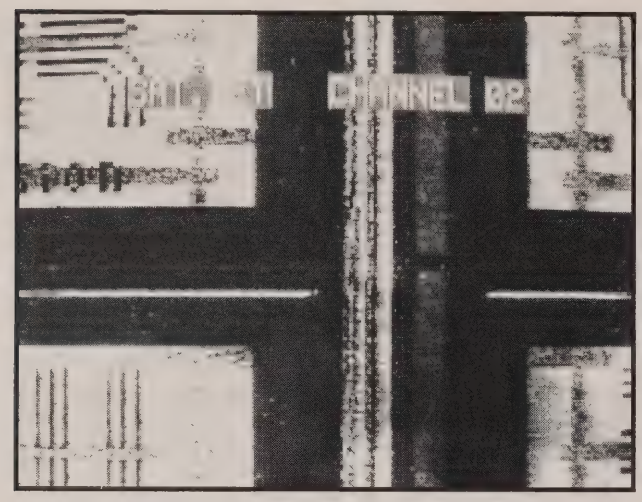


Fig. 5-16. EBU sound-in-syncs on Eurovision channels, (Eutelsat, 7° East).

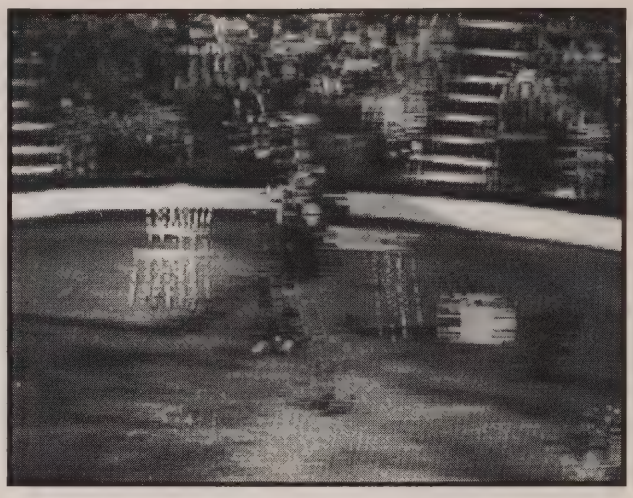


Fig. 5-17. Discret-encrypted broadcast.

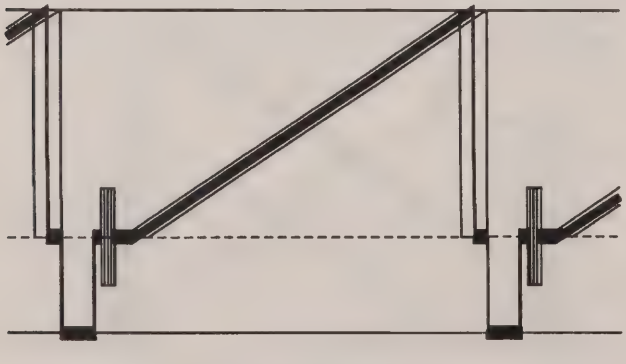
but normally no subcarriers are present. The modulated pattern of audio digits is clearly seen in the pulse-cross display (Figure 5-16). A development of the basic system, known as SSiS, supports stereo sound transmission.

Systems Which Modify Picture Timing

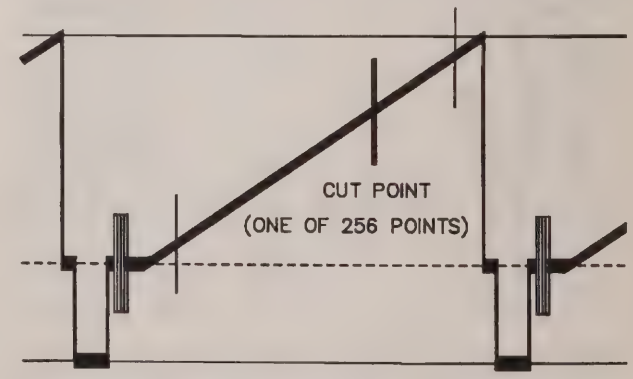
Discret. The original Discret system was developed by Philips' Portenseigne subsidiary in France, for low-cost SECAM encryption of the Canal Plus terrestrial pay-TV channel. It was first seen on satellite with TV5 (now in clear PAL), and subsequently employed by Canal Plus and Canal j (both now using Nagravision/ Syster) on the Télécom satellites. RAI-Uno and RAI-Due (Eutelsat) have also used a version of Discret at times.

Discret works by switching discrete analogue time delays into the active line, either zero, one or two delays of just under 1 µs each. Syncs are not disturbed (Waveform 5-7). The pattern of time shifted lines repeats over a cycle of one or more fields under control of a pseudo-random binary sequence (PRBS) which in the decoder is seeded by the combination of a unique key stored on chip, together with an eight-digit code word entered by the user. Later decoder versions apply the time-shift in the digital domain. The small delays result in a line displacement of about 2cm on the TV screen (Figure 5-17). This has the advantage (in some applications) of rendering the picture recognizable while still being quite uncomfortable to watch. The audio can be scrambled by spectrum inversion, or transmitted in the clear.

VideoCrypt. Here the more hardware-secure principle of active-line rotation is employed. The encoder selects a cut point within each active line (Waveform 5-8), one of 256 possible



Waveform 5-7. Discret system introduces pattern of switched active line delays.



Waveform 5-8. Selection of cut point, VideoCrypt.

Fig. 5-18. VideoCrypt line rotation (Sky Movies, Astra, Tp. 16).

cut points according to an 8-bit word derived from a PRBS generator. The line is then reassembled on either side of the cut point, the second part being transmitted before the first (Table 6-9). This is described as a "cut and rotate" operation. On the next and subsequent lines different cut points are used, so that all vertical information in the picture is broken up, stepped back and forth across the screen with each line (Waveform 5-10) and in a sequence that changes from field to field. Horizontal structure is retained—horizons, subtitle bars and programme menus (though not their text) are easily recognized. Syncs are normal (Figure 5-18) and audio is not encrypted.

The decoder performs the complementary cut-and-rotate operation, patching each line back together at the correct point to reconstruct the original picture. We shall not attempt to explain here the complexities of cryptography, but in simple terms data for the cut points is conveyed by a combination of two keys: one derived from data transmitted in the VBI (the vertical blanking interval or field suppression period of the transmission), the other distributed by a "smart card" mailed to the subscriber every three to six months. In this way all the decoders are identical. Fig. 5-19 shows the VBI data on a waveform monitor. The five lines at the center of the display are those involved. Looking closely at the photo reveals four lines of full-amplitude (black to white, 700mV peak to peak) data, followed by a reference line at peak white. Originally a black-level reference line was also included, but pressure on VBI space has meant that most VideoCrypt broadcasters transmit only the four data lines—the appropriation of even four VBI lines per field limits the number available for teletext, cue and test signals. Also apparent from the display is the

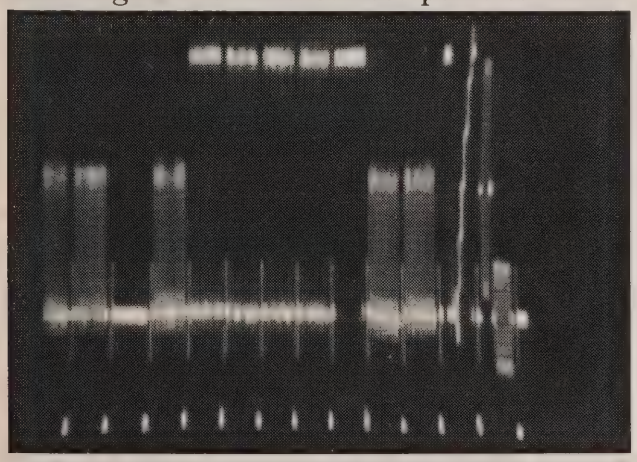
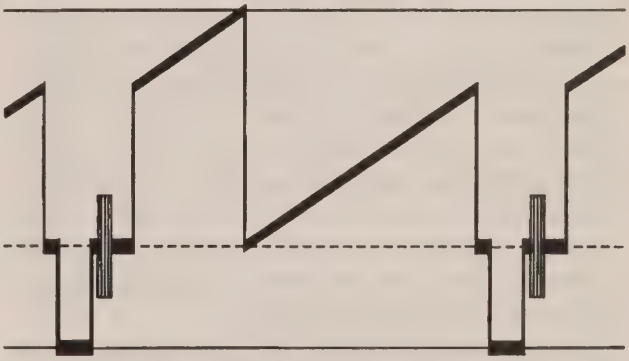
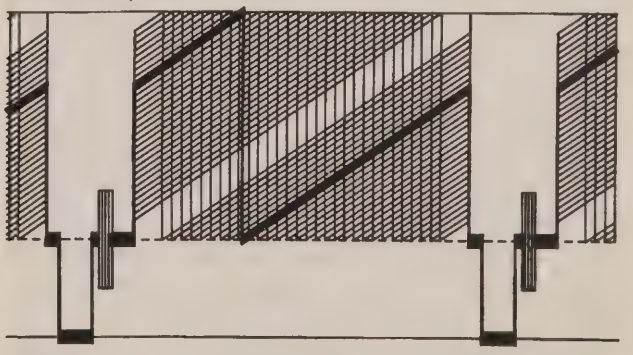


Fig. 5-19. VBI waveform showing VideoCrypt-I data lines (Sky: The Movie Channel, Astra Tp. 18).



Waveform 5-9. VideoCrypt rotates picture information about cut point, transmitting second part of active line before first part.



Waveform 5-10. All-lines display of VideoCrypt signal shows superimposed position of pseudo-randomly selected cut points.

lower data rate compared with the adjacent Teletext lines. This low speed and high amplitude, combined with error correction, makes VideoCrypt data extremely rugged—decoding is unaffected by low signal-to-noise ratios.

Thomson/Alcatel have had professional line rotation equipment available for some years, but the advent of inexpensive digital video processing chips allowed the implementation of this inherently secure scrambling system along with a mathematically secure encryption process (using News Datacom's RSA algorithm) at a very low cost. Originally developed for the Sky Movies channel, VideoCrypt was introduced via add-on decoders manufactured by Thomson and Philips, but in 1990 Amstrad developed the first VideoCrypt IRD, the SRD 400, followed within a year by Pace and other leading manufacturers. These give British viewers access to all of the UK's Astra channels, and many foreign ones, for a total hardware outlay of less than £200 ($300), including a 60cm dish and LNB.

VideoCrypt is now the de facto encryption standard for English-language PAL satellite broadcasts in Europe, and a number of UK-based Astra programmers share Sky's subscriber management operation at Livingston, Scotland, as members of the Sky Multichannels package. Monthly subscription fees range from about £10 ($15) for the basic tier to £23 ($34.50) for the full premium service.

Near-clones of VideoCrypt have recently begun to appear, offering programmers compatibility with standard IRDs without dependence upon Sky, NDC or Thomson, and apparently avoiding the infringement of VideoCrypt patents. One such system, designed in Britain, is marketed under the name Enigma, or Key TV.

VideoCrypt II is a development of VideoCrypt which apparently offers enhanced security. It can co-exist with standard VideoCrypt (or VideoCrypt I) on the same transmission, sharing the video scrambling process but carrying quite separate entitlement data, and so supporting an independent subscriber base. So certain of the Sky MultiChannels members, marketing their programmes to the UK via VideoCrypt I, are able simultaneously to serve mainland Europe via VideoCrypt II. The penalty for using both systems together is a serious reduction in VBI capacity: VideoCrypt II data also requires four lines, which are transmitted immediately before the four VideoCrypt I data lines in each field, as can be seen in Fig. 5-20.

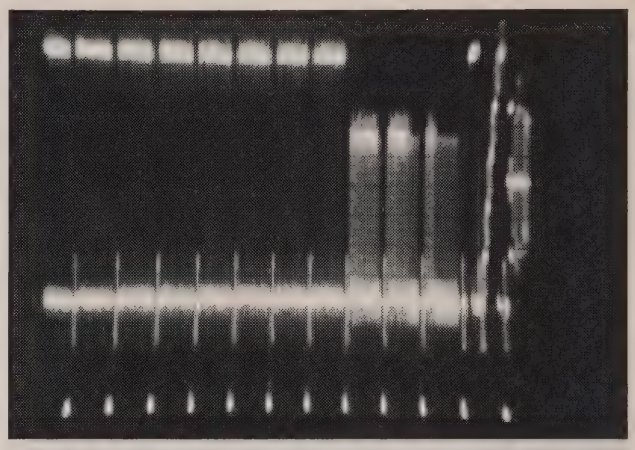


Fig. 5-20. VBI waveform showing VideoCrypt-I and -II data lines (Discovery Channel, Astra Tp. 41).

Smart Card piracy is now a serious problem for VideoCrypt. Although outlawed in the UK, counterfeit cards are readily obtainable, and are openly marketed throughout Europe. So far, these cards will work at best for some months before being disabled by the system. With every new release of official smart cards containing a new countermeasure, it threatens to be only a matter of time before the hackers exhaust the resources of the system, and create the immortal card.

Cryptovision. This is the only other PAL-based line-rotation system currently in European satellite use. Developed by Norway's Tandberg Telecom, it is used by SSVC, the Services Sound and Vision Corporation, on an Intelsat East Spot Beam transponder on the 27.5 degrees West Longitude satellite. SSVC has taken over British Forces broadcasting to Europe from the original operator BFBS.

Nagravision. Designed by Swiss company Kudelski, well known for its Nagra professional audio tape recorders, versions of this system are used by the Canal Satellite programme bouquet (including Canal Plus itself) in France, the Canal Plus affiliates in Germany (Premiere), Switzerland (Teleclub), Spain (Canal Plus

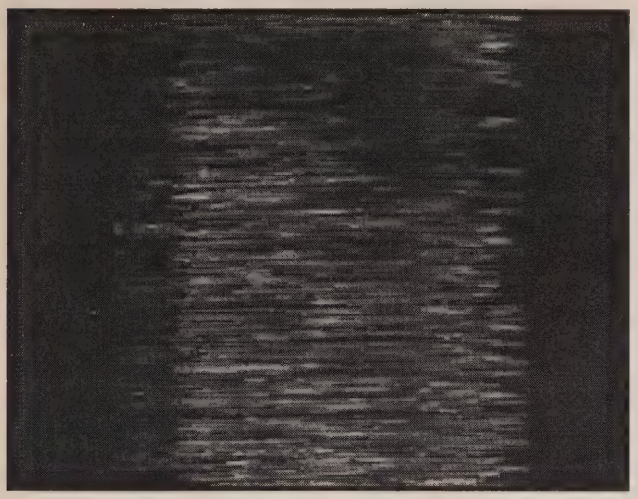


Fig. 5-21. Nagravision Professional full-field line shuffling.

España) and Africa (Canal Horizons), by the Spanish independent commercial channels on Hispasat and Astra, and by Italy's Canale Cinque on Intelsat. Carrying digital processing a stage further the professional system employs a field store in its scrambling process, storing a full field and then transmitting the lines in a "shuffled" sequence. In this way there is no horizontal displacement, so vertical lines remain intact; information from any horizontal strip of the picture remains in horizontal position but is redistributed vertically over the whole field. Figure 5-21 shows the Spanish Telecinco (Tele 5) logo. The "all lines" waveform is indistinguishable from standard PAL.

The reverse process takes place in the decoder, with lines being read from a field store in the correct sequence to reconstruct the picture, under the control of a PRBS seeded by the encryption system. Again the syncs are undisturbed and the VBI is used for transmission of the encryption and authorization data. The field store requirement makes the decoders inherently more expensive than the VideoCrypt units, which only store one line at a time.

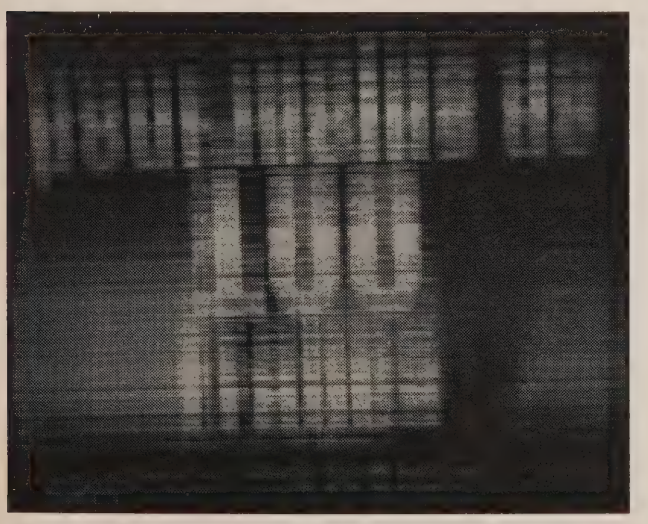


Fig. 5-22. Nagravision Syster part-field line shuffling.

The version used for direct-to-home (DTH) services requires storage of only a partial field, economising on video memory chips (Fig. 5-22). These "Syster" (originally "Systeme Terrestre") decoders are made in France by Sagem/ Eurodec.

MAC

Most of the European DBS services, that is 12 GHz high power broadcasts under the WARC DBS plan, plus some of the low and medium power DTH channels, use a form of MAC. Multiplexed Analoge Component transmission is not a scrambling system, nor is it some kind of half-way house to HDTV, it is simply an alternative method of coding for transmission which combines the luminance, colour and audio parts of a TV signal (the components) in a different way to conventional PAL, SECAM or NTSC.

MAC Features

MAC was devised by engineers at Britain's Independent Broadcasting Authority (now National Transcommunications Ltd.) as a way of eliminating the interference between the brightness and colour signals which has always been a feature of colour TV since NTSC was invented. NTSC and its derivatives (PAL and SECAM) combine colour information into the composite TV signal by frequency-division multiplexing the colour difference signals (variously I and Q, U and V or R-Y and B-Y) using an amplitude- and phase-modulated in-band subcarrier at 3.58 MHz (NTSC) or 4.43 MHz (PAL), or two frequency-modulated subcarriers (SECAM). These are decoded in the TV to derive the RGB signals which drive the picture tube.

Any carrier within the luminance band will appear as patterning on the picture. The colour

subcarrier frequency and phase are designed for minimum visibility, but even with filtering (which also limits resolution) a crawling dot pattern, cross luminance, is visible on colour edges. The converse effect, cross colour, happens when high-frequency luminance transitions are mistaken for colour information in the TV, giving rise to spurious areas of strobing colour.

Instead of this frequency-division multiplex, MAC transmits the analogue components sequentially on each line in a time-division multiplex. But to retain line and field frequencies unchanged the components must first be time-compressed, so they will fit into the same 64 µs line time of the standard signal. The luminance line is compressed by a factor of 3:2, increasing its bandwidth (for a given resolution) by the same factor; the two colour-difference components need less resolution so a greater compression, 3:1, is used, and they take turns on a line-by-line basis. The overall video bandwidth is thus increased to about 8.5 MHz for a 625-line source of 5.75 MHz luminance bandwidth. The wider screen format of 16:9 aspect ratio can be handled by an increase of transmitted compression ratio and video bandwidth (to 10.5 MHz), and MAC decoders can be given the capability of displaying a "compatible" 4:3 picture from a 16:9 transmission by a "pan-and-scan" process.

MAC's designers also took the opportunity to include the sound signal in the time-division multiplex, so avoiding the need for sound carriers or subcarriers. As many as four high grade audio channels can be accommodated in a D2-MAC transmission, six in B-MAC or eight in C-MAC or D-MAC. All MAC systems use digital coding for the sound channels along with a variable amount of data capacity which is available for encryption, addressing, text or data broadcasting; the different species of MAC (B-MAC, D2-MAC Packet, etc.) refer to alternative methods of modulating and coding the sound/data burst.

Figure 5-23 shows the appearance of MAC when displayed on a PAL receiver with external syncs.The photo is of a clear D2-MAC transmission, which has half of the D-MAC data rate.

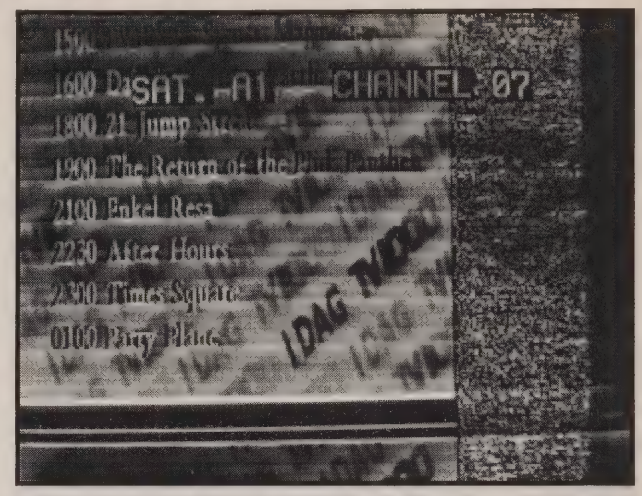
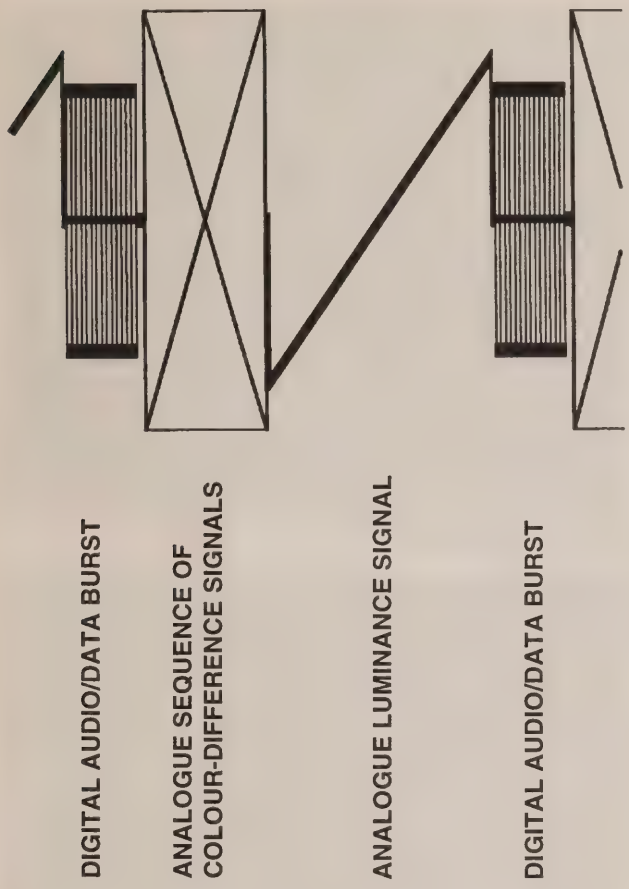


Fig. 5-23. D2-MAC on PAL receiver syncs (TV1000, Astra Tp.7).

Waveform 5-11 shows the components of the D2-MAC signal in the time domain. The screen shot shows the compressed (tall and thin) luminance at left, followed by the noise-like audio/data burst and then the compressed colour information dimly visible to the right.The streaking is due to mis-clamping in the PAL receiver. In fact the MAC line is considered to begin with the data burst, the first few bits of which contain the synchronization word. This of course means nothing to a PAL receiver (or even one for a different species of MAC), so without the appropriate decoder even a clear MAC signal is effectively scrambled.

MAC Variants

A-MAC (data by subcarrier) and C-MAC (RF data modulation) are now obsolete, all current MAC satellite transmissions using a version of the baseband data systems B-MAC, D-MAC or D2-MAC. B-MAC (Waveform 5-12) employs 2-level and 4-level PSK modulation with a basic symbol rate of 7.109375 MHz, and codes the audio using Dolby's ADM (Adaptive Delta Modulation). The system is licensed to US company Scientific Atlanta, and a 525-line version is also available for NTSC source material. Interestingly S-A's B-MAC decoders employ analogue CCDs (charge-coupled devices) rather than digital line stores for time-manipulation. D-MAC utilizes a packet data structure with duobinary

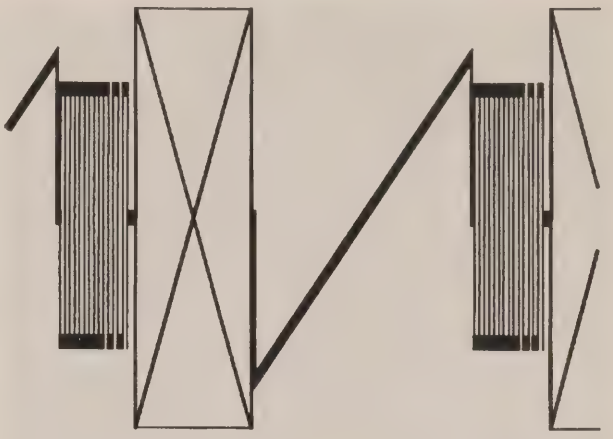


Waveform 5-11. D-MAC is a time-division-multiplex of digital audio and data with time-compressed analogue luminance and chrominance and colour difference signals. (D-MAC differs from D2-MAC in having twice the data rate).

(three level) coding at 20.25 Mb/s, while D2-MAC halves this to 10.125 Mb/s to permit AM VSB cable distribution. The difference in bit-rate is readily seen on the pulse-cross display: compare Figure 5-24 (D-MAC) with Figure 5-23 (D2-MAC). S-MAC (Studio MAC) is an American production standard not used for satellite transmission.

MAC Scrambling Methods

The digital line storage and time-manipulation processing necessary for MAC decoding lends itself well to the time-shifting scrambling variants. This is a "plus" for MAC in the sense that little additional decoder circuitry is required for decryption (or a minus if transmission in clear is considered!) The necessary conditional access data can be accommodated in the multiplexed data packet structure of the MAC signal.



Waveform 5-12. B-MAC uses a different coding method for the audio/data burst.

B-MAC as always is a special case and has its own proprietary scrambling technique. This involves audio/data encryption and progressive line translation of the entire multiplex within the line suppression period (horizontal blanking interval) of the data burst, according to a pseudo-random sequence (Waveform 5-13). The step-wise application of discrete delays gives the scrambled video a unique "zig-zag" appearance on the pulse-cross display (Figure 5-25). Video security is generally re-

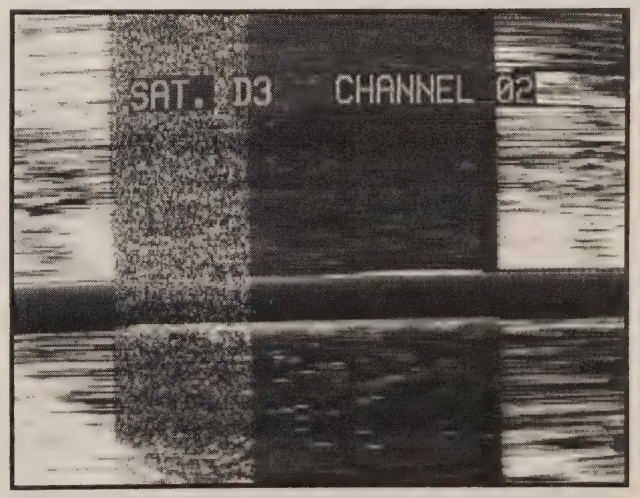


Fig. 5-24. Eurocypher D-MAC on PAL receiver syncs (BSkyB via Marcopolo, 1991).

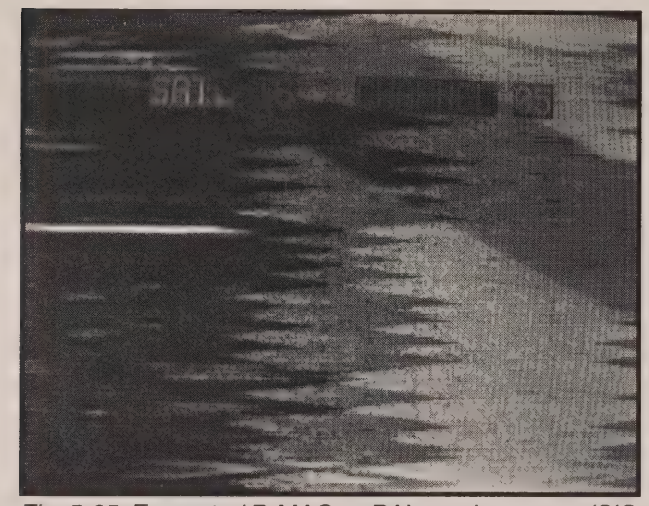
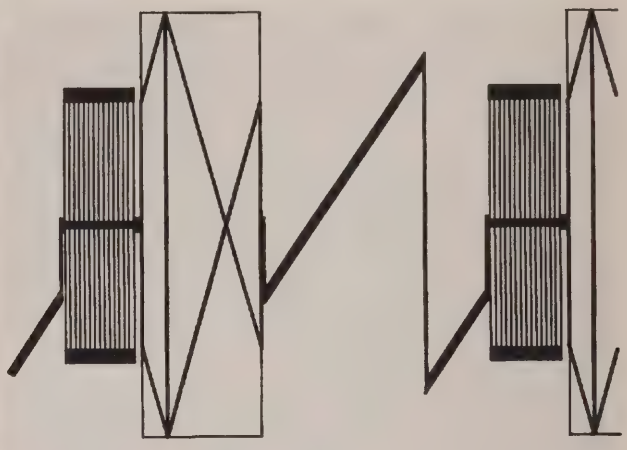


Fig. 5-25. Encrypted B-MAC on PAL receiver syncs (SIS, Intelsat).

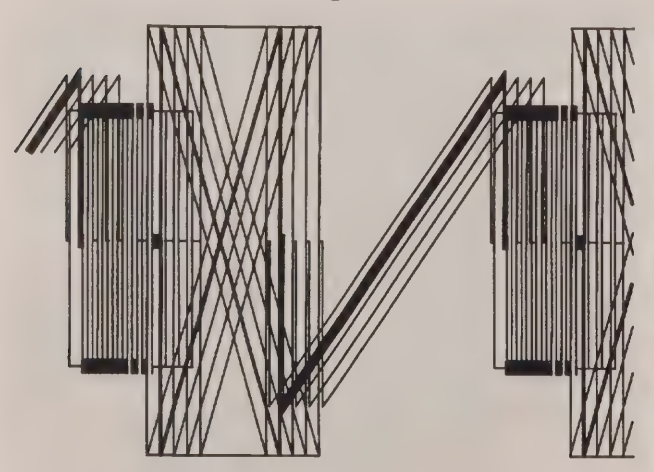


Waveform 5-14. Double-cut MAC scrambling by independent cut and rotate operations on chrominance and luminance components.

garded as lower than that of the cut-and-rotate MAC variants, it being vulnerable to hardware assault. Unencrypted B-MAC can be recognized by the uncoded reference burst within each data period. B-MAC has its own system of subscriber billing, messaging and teletext, extensively used by the Australian HACBSS DTH services. Encrypted B-MAC is used in Europe by the closed user networks SIS and SIP, by France Télécom for videoconferencing, and by AFRTS (in the 525-line version) for distribution in Germany, Italy and Turkey.

D-MAC and D2-MAC scramble by line-rotation (like VideoCrypt), with the option for "double-cut" scrambling (Waveform 5-14), using different cut points for the luminance and colour-difference components. The application of cut-and-rotate, combined with the lack of conventional sync pulses in the MAC multiplex, make for a totally unintelligible display (Figure 5-26) on a PAL receiver. On a MAC receiver without authorization the result may be a scrambled picture and noise in the sound channel, or a blank screen and silence, according to the decoder. Attempting to apply MAC decoding to a PAL signal produces the horizontally stretched result of Figure 5-27.

Three main types of encryption are used in conjunction with the double-cut and rotate scrambling of D-MAC and D2-MAC signals. For



Waveform 5-13. B-MAC scrambling employs progressive backward and forward line translation of the MAC multiplex.

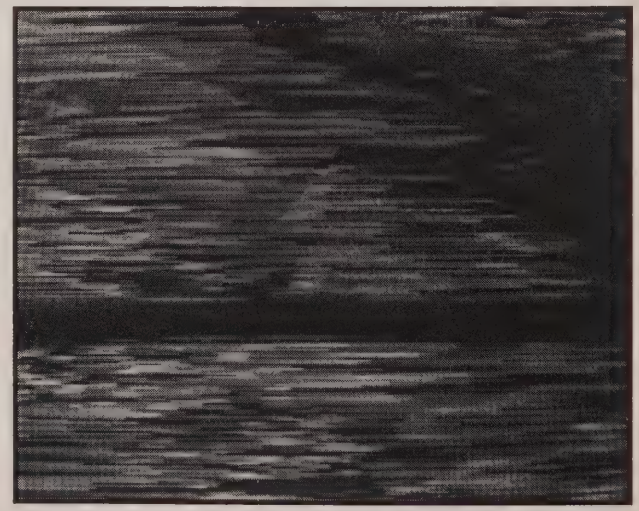


Fig. 5-26. Eurocrypt D-MAC on PAL receiver without syncs.

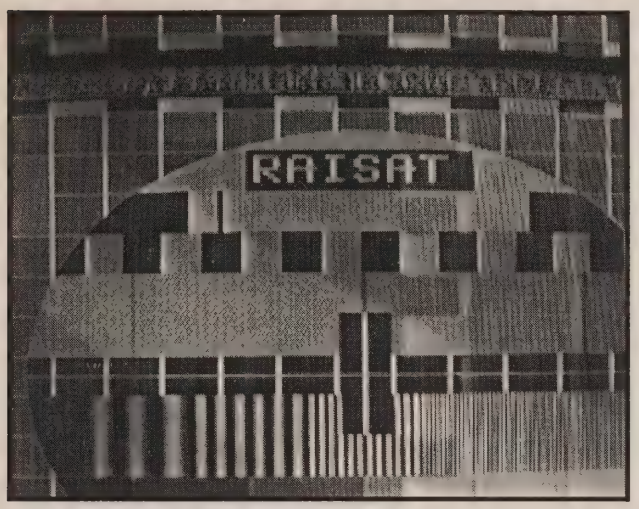


Fig. 5-27. PAL signal on D2-MAC receiver.

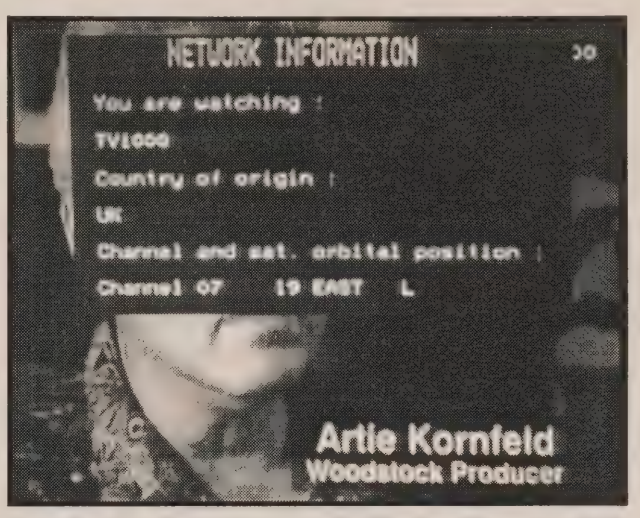


Fig. 5-29. Eurocrypt-M on-screen status display, TV1000.

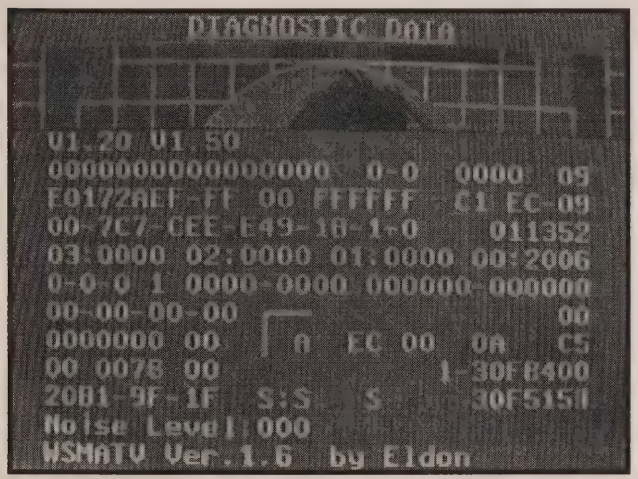


Fig. 5-28. Eurocypher on-screen diagnostics display (BSkyB, 1991).

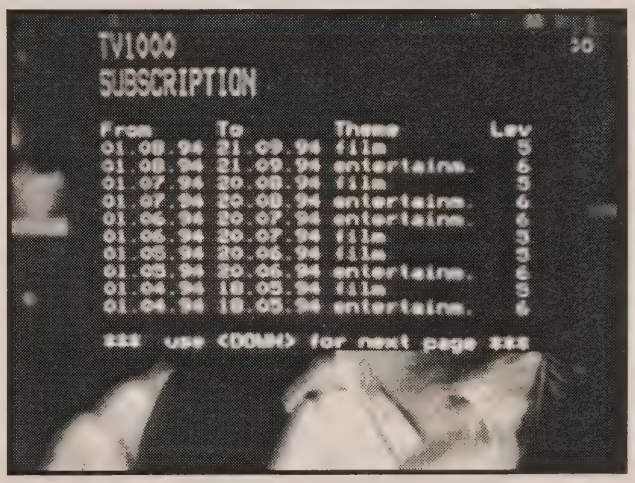


Fig. 5-30. Eurocrypt-M on-screen subscription display, TV1000.

its Marcopolo broadcasts, Britain's abortive high-power DBS project BSB employed D-MAC with Eurocypher, a version of General Instruments' VideoCipher technology adapted for 625-line MAC. This was based on the secure DES algorithm and placed a uniquely addressable ACM (access control module) into every decoder, which generated all the necessary on-screen messages (Figure 5-28). Eurocypher fell out of use with the take-over of BSB by Sky Television (now BSkyB), who sold the UK's two Marcopolo satellites to DBS groups in Norway and Sweden.

Philips, working with MAC chip designer Nordic, supports the Eurocrypt system. This provides features broadly similar to Eurocypher, but is not compatible with it. Two versions are available to programmers: Eurocrypt-M is favoured by France, Germany, the UK and the Astra and Intelsat-based Scandinavian services of the TV3 group (Figures 6-29 and 6-30); the Scandinavian high power DBS operators on the Tele-X, Thor and Sirius satellites prefer Eurocrypt-S, though they have recently moved away from D-MAC in favour of the more rugged D2-MAC. Both flavours of Eurocrypt support smart-card technology, and the latest IRDs incorporate software to handle both systems.

A third contender for D-MAC or D2-MAC encryption is News Datacom's VideoGuard. Its

scrambling and smart-card operation are similar to Eurocrypt, but it incorporates NDC's own encryption algorithms as used in their PAL-based VideoCrypt system. Had MAC transmission been imposed on BSkyB's Astra channels, this is the system the group would have adopted.

Like VideoCrypt, the smart-card based Eurocrypt-M has been a target for the hackers, driven principally by demand for unauthorized access to FilmNet and the late-night erotic material carried on the TV1000 channel. Pirate cards are sold throughout Europe.

MAC and the Eurocrats

MAC was only one of several "evolutionary" proposals for improving TV quality, short of a move to true (Hi-Vision-style) HDTV, but it found favour with the EBU on account of its very incompatibility with PAL, through those European governments who saw it as a way of keeping a distinct DBS technology for Europe, a protectionist measure against Far Eastern receiver imports. The European Commission passed a directive making MAC mandatory for European DBS. This directive had no power over DTH transmissions through fixed-service (FSS) satellites like Astra, as these do not transmit in the frequency bands allocated for broadcast services. This allowed medium-power multichannel PAL DTH operations (like Astra) to flourish unencumbered, while loading high power projects with costly and underdeveloped technology.

In a PAL world MAC seems to offer little of real practical advantage for DBS. On most types of programme material the cross-colour and cross-luminance improvement is simply not seen. Most programme sources are PAL, or 16mm film (with lower resolution than PAL), or standards-converted NTSC. Even when component transmission can be preserved from source, as with 35mm motion-picture material, many viewers will use the composite PAL re-coded UHF output from their MAC receivers, yielding poorer pictures than if the original transmission had been made in PAL.

MAC's audio capacity is also severely curtailed when encryption and data transmission are used, in some cases to two full specification sound channels, or one stereo pair. These are indeed of digital quality, but that carries little weight against the typical maximum of six to eight companded Wegener channels available with a PAL transmission. Even MAC's claims of threshold and signal to noise advantages have been silenced as the receiver/decoders' real performance has become apparent—the most significant picture improvement is due to the greater carrier to noise ratios achieved with the high power satellites. The G/T difference between a 60cm Astra dish and a 35cm DBS dish might be 5 dB, but the DBS satellite transmits 10 dB more power. The DBS viewer thus gains a net 5 dB advantage in rain margin and signal to noise ratio.

In the early 1990s, a new directive threatened, with the promotion (through the Eureka 95 Project involving consumer electronics giants like Thomson, Philips and Nokia) of MAC as a "compatible" stepping-stone to HDTV. HD-MAC uses D-MAC or D2-MAC data capacity to carry additional picture information (digital assistance), combined with increased compression ratios and a greater video bandwidth to give a wide-screen, line-doubled and field-rate doubled pseudo-HDTV picture. However sanity prevailed with the realization that the next significant step in broadcasting must involve all-digital transmission. Digital compression formats based on the MPEG-2 standard can squeeze four, six or more TV channels (the number depends upon the information density of the source material) into a single 27 or 36 MHz transponder without visible impairment. They can also handle "wide-screen" aspect ratios. Successful demonstrations of digital compression technology at last showed MAC to be a blind alley.

In 1994, MAC's one remaining "good trick" is its ability to switch time-compression ratios to transmit a 16:9 aspect ratio "wide-screen" picture. When used correctly with a true wide-screen source (TV or motion picture) and a 16:9 display tube (or a 4:3 tube in "anamorphic" vertically underscanned letterbox mode) this can be impressive. But in the absence of sufficient panoramic source material some French and German broadcasters are electronically

up-converting 4:3 programmes for 16:9 transmission in MAC. This results in pictures with very poor definition, combined with clipped heads, feet and captions. The effect is similar to the vertical overscanning enjoyed by many owners of 16:9 TVs—the scan formats are switchable—reducing the active picture area's resolution to something resembling the BBC's pre-war 405-line system, superseded at the beginning of the 1970s.

PAL has its own version of 16:9 capability, a digitally-assisted letterbox format called PALplus, which has found favour with some German channels and the UK's terrestrial Channel 4, as a compatible interim wide-screen measure prior to the introduction of digital TV broadcasting.

Digital Broadcasting

In 1994, digital satellite TV broadcasting is in its infancy, with the first DBS systems having just begun in the USA, and Europe's DVB Group still hammering out the details of a standard for Europe. MPEG-2 compression is the basis for this standard, with a hierarchy of modulaion formats, bit-rates, and compression factors according to cable or satellite distribution, transponder/channel bandwidth and source information content. A typical satellite transponder might employ QPSK modulation with a transmission rate of 49 Mb/s carrying four or more TV services, each with stereo sound. TV distribution operations requiring an early entry into the bandwidth economies which digital offers, have had to choose from existing systems such as NTL/Scientific-Atlanta System 2000, GI's DigiCipher or CLI's SpectrumSaver. Such operators include FillmNet's MultiChoice Kaleidoscope and Orbit's Arabsat-based offerings.

Scrambling of digital broadcasts differs fundamentally from the analogue techniques so far discussed. To an analogue receiver a digital transmission is indistinguishable from noise; even a digital receiver is unable, without the appropriate decoding instructions, to output anything resembling a TV picture—the demodulated data is simply an apparently random stream of ones and zeros, which could equally be coded with radio programmes, stock market prices or computer games—the notion of scrambling to render a picture unwatchable becomes redundant. With few digital receivers on the market, their cost alone is a barrier to piracy: Orbit's decoder (manufactured by Scientific-Atlanta) is available to DTH homes in the Middle East for a fee of $10,000, which includes the first year's programming. But in a full DBS operation (due to begin in Europe as early as 1995) IRDs will be plentiful and inexpensive, and as with analogue it will be important to incorporate a secure and preferably (for the consumer) standardized encryption system. At this level there need be no difference between the analogue and digital process—in fact the U.S. DBS service DirecTv uses a version of NDC's VideoCrypt conditional access subsystem. At present Europe's broadcasters are debating whether Europe's equivalent should be Simulcrypt, a VideoCrypt-like proprietary system backed by the major pay TV programmers, or Multicrypt, a Eurocrypt-like "open" system proposed by France Télécom.

Chapter 6

Audio Reception Techniques

Every satellite video transmission includes a composite baseband, created by multiplexing signal frequencies together at the uplink. These frequencies range from near zero to about 10.5 MHz. Certain frequencies, called main carriers, may include monochrome and color video information and audio signals. Auxiliary signals sometimes accompany the primary information sent on main carriers. Subcarriers transmit these auxiliary signals. Since subcarriers are referenced to the main carrier, they can exist only if the main carrier is transmitted.

NTSC video uses a 3.579545-MHz chroma color subcarrier to transmit color information, while PAL uses a 4.43361875-MHz subcarrier. (Argentina's PAL-N and Brazil's PAL-M use 3.57561149 MHz and 3.58205625 MHz, respectively.) SECAM transmits color information using dual color subcarriers: 4.40625 (red) and 4.250000 MHz (blue). A guard band (about 4.2 to 5.0 MHz for NTSC or 4.5 to 5.3 MHz for PAL and SECAM) separates the monochrome and color video signals from the audio subcarriers. It is possible to transmit up to two dozen audio subcarriers in the 5.0 to 8.5 MHz frequency range.

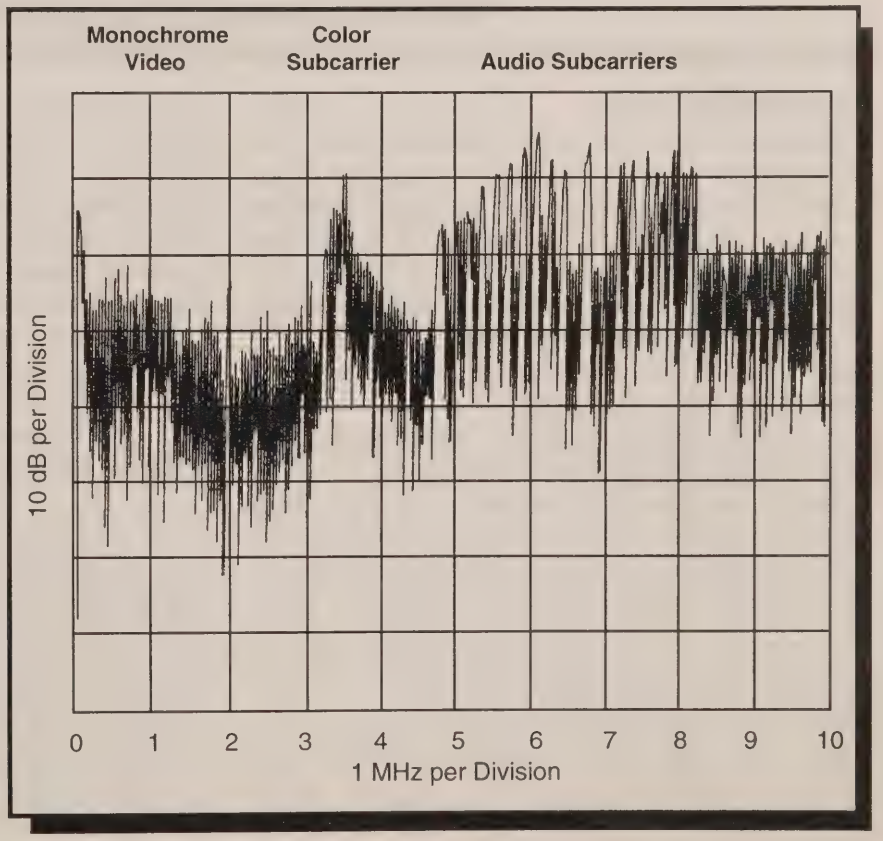


Fig.6-1. Spectral display of baseband video signal.

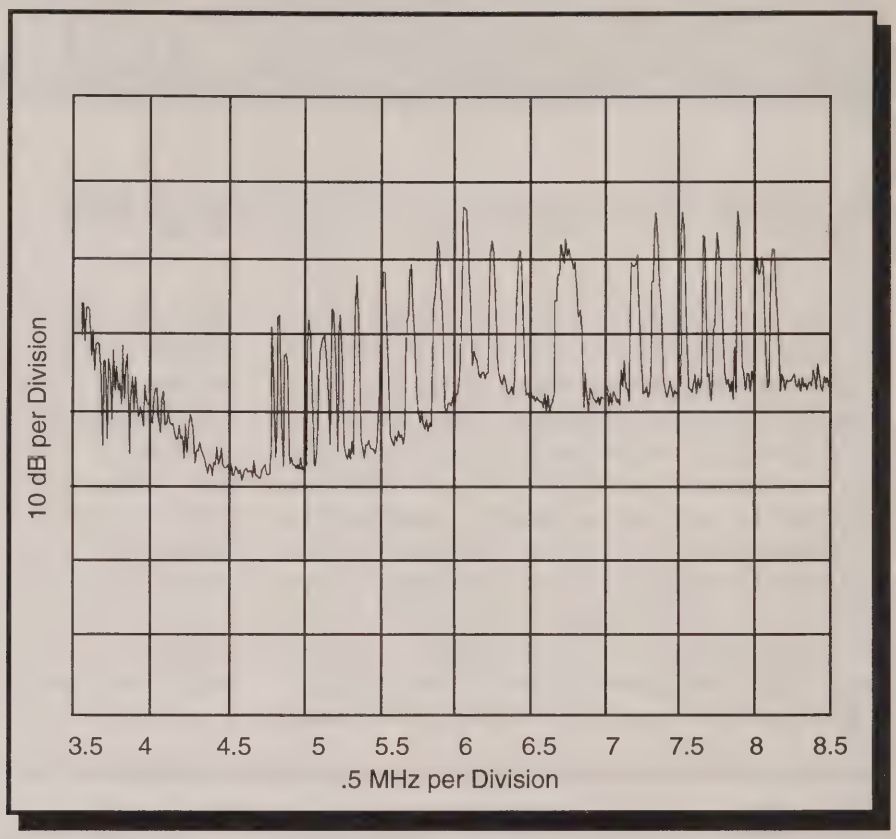


Fig. 6-2. Subcarrier portion of baseband spectrum with auxiliary stereo subcarrier pairs and monaural TV audio at 6.8 MHz.

FM Squared (fm^2)

Alternatively, if an active but unmodulated main carrier is substituted for an active video signal, it is possible to use a single satellite transponder to transmit dozens of audio and data subcarriers in the 0.15 to 8.5 MHz frequency range. Wegener Communications has developed a system, called *FM Squared (fm^2)*, that uses this transmission technique. SpaceCom Systems uses this system to transmit a wide range of audio services on the Spacenet III and Galaxy IV satellites.

The IF bandwidth is limited to 16 MHz. This provides immunity to terrestrial interference, which typically is received by the earth station at intervals offset ±10 MHz from the main carrier. The narrow fm^2 bandwidth also increases the threshold performance of the receiver by more than 2 dB.

Any mix of audio and/or data subcarriers, from a 3.5 kHz voice channel to a T1 data channel, can be transmitted and received at a cost very affordable to both the broadcaster and the end user. The maximum number of carriers which can be transmitted in a given application depends on the mix of services carried. Twenty-eight 15 kHz audio channels can be placed on a transponder. But, while a 15 kHz audio channel requires 180 kHz spacing, a 7.5 kHz audio channel requires only 90 kHz spacing, so two 7.5 kHz carriers alternatively may be substituted for any one 15 kHz carrier.

Discrete Stereo

Broadcasters use several modulation methods to transmit stereo audio services on satellite subcarriers. Discrete stereo uses two separate audio subcarriers to transmit a single stereo service. One subcarrier carries the left stereo channel, the other relays the right stereo channel. Discrete stereo transmissions often use a narrower deviation level than the other formats, which requires narrowband audio filters for best reception.

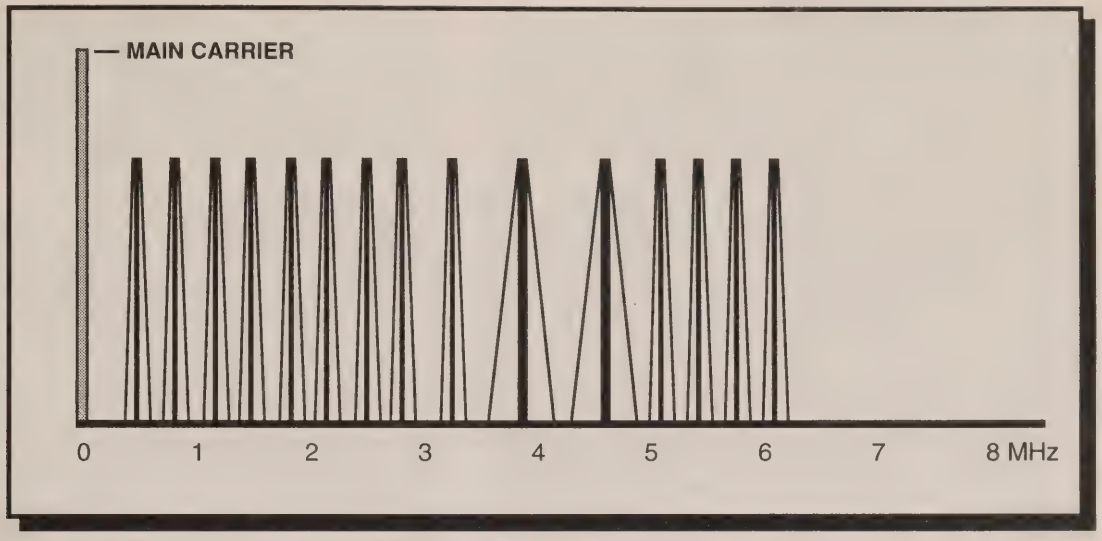


Fig.6-3. The FM Squared (fm^2) signal is characterized by an unmodulated main carrier with multiple audio and/or data subcarriers.

Multiplex Stereo

Multiplex stereo uses one subcarrier to send the left and right stereo sound channels. First, the left and right stereo channels are changed into a composite signal. This signal represents the sum of the left and right channels (L + R). A second composite signal represents the left minus the right (L - R) stereo channel. Using FM modulation, the L+R signal transmits within the 50 Hz to 15 kHz spectrum of the subcarrier's audio baseband. The L - R sound information transmits on a double sideband signal, which means that it occupies the bands on both sides of the carrier frequency produced by modulation. This frequency has a suppressed AM carrier centered on an audio baseband frequency of 38 kHz. The satellite receiver's mixer sums the L + R signal and the L - R signal to produce the left stereo channel. The mixing circuit subtracts the L - R signal from the L + R signal to produce the right stereo channel.

Matrix Stereo

Matrix stereo, like multiplex stereo, first converts the separate Left and Right stereo channels into L + R and L - R signals. The matrix stereo system, however, uses two separate audio subcarriers to transmit the stereo sound. Again, the receiver's mixer circuit sums the L + R and L - R signals for the left stereo channel and subtracts the L - R signal from the L + R signal for the right stereo channel.

Understanding deciBels (dBs)

A deciBel is a unit of measurement that expresses ratios logarithmically. The term was conceived in the early days of communications so Bell telephone technicians could rate line performance. In the audio field, decibels refer to changes in sound levels.

dB	Multiplier
0	1.0
1	1.2
2	1.6
3	2.0
4	2.5
5	3.0
6	4.0
7	5.0
8	6.3
9	8.0
10	10.0
11	12.6
12	15.8
13	20.0
14	25.1
15	31.6
16	40.0
17	50.2
18	63.2
19	80.0
20	100.4

Signal-to-Noise Ratio

The formula dB S/NR expresses audio performance. The S/NR (or signal-to-noise ratio) value indicates the ratio of signal power to noise power in a frequency bandwidth. The more signal, the crisper and clearer the audio. Most monaural videocassette recorders achieve an audio performance level of 48 dB S/NR; cable stereo delivery systems reach approximately 55 dB S/NR; audio cassette players reach approximately 65 dB S/NR; broadcast FM radio signals reach 68 dB S/NR; phonographic turntables reach 70 dB S/NR; high fidelity stereo VCRs reach about 80 dB S/NR; and compact disc players can reach 90 to 95 dB S/NR.

All the analog subcarrier formats now used rate far below compact disc players on the S/NR scale. Multiplex systems typically achieve an S/NR of about 60 dB, discrete systems 62 db, and matrix systems 65 dB. However, new methods recently have been developed to deliver digital signals with levels close to those of compact disc players. Digital stereo converts the left and right analog stereo channels into continuous flows of digital information called *bit streams*. These streams either transmit on one or more audio subcarriers, or use the video's *horizontal blanking interval* (HBI). Signals transmitted on the Leaming Industries *Studio Line* and Wegener Communications' *Panda I* audio subcarrier systems achieve SN/R levels near 90 dB.

Companding is a method of compressing the dynamic range of audio in order to transmit it within a relatively narrow bandwidth. At the receive end, an expander circuit restores the dynamic range of the signal. Companding makes it possible to achieve higher SN/R levels.

Audio Sound-in-Syncs

Instead of standard audio subcarriers, a few satellite services use sound in sync (SiS) modulation techniques to transmit audio information. These methods multiplex audio information into the line suppression segment of the video waveform's horizontal blanking interval. The main advantage of the SiS mode of audio transmission is that the transponder can deliver its full power to the main video carrier. Eliminating the subcarriers also permits the use of advanced threshold extension techniques at receiving earth stations. The main disadvantages of the SiS method are the higher costs and increased complexity of transmitting and receiving circuitry.

Pulse Code Modulation

Various Japanese FSS and DBS satellite services transmit the sound portion of the TV programming—as well as various auxiliary audio services—through the use of "Type A" and "Type B" pulse code modulated (PCM) audio subcarriers (5.72727 MHz). Depending on the bit rate used, satellite-delivered PCM audio can achieve a theoretical dynamic range of 80~98 dB S/N, with 98 dB comparable to today's compact disc players.

Fig. 6-4. PCM audio system parameters.

Japanese PCM Parameters	MODE A	MODE B
Bandwidth:	15 kHz	20 kHz
Sampling Frequency:	32 kHz	48 kHz
Quantization bit:	14bit (compressed to 10 bit)	16 bit (linear)
Multiplex Channels	4	2
Data capacity	480b/s	240b/s

Digital fm³ Technology

Developed by SpaceCom Systems, *fm³* (pronounced "fm cubed") is a proprietary method for transmitting many digital audio and data services over a single satellite transponder. In an fm³ system, many digital channels are time division multiplexed and subsequently modulated using a matrixed multi-level frequency modulation scheme. The service first became available on July 1, 1991.

Some of the more important features of fm³ include full addressability, electronic mail capability, remote data rate upgrades, and a remotely configurable interface standard. Users of fm³ technology can use low-cost downlink equipment and small aperture (.75m) receive antennas.

Any mix of digital and/or data channels, from a 3.5 kHz voice channel or 15 kHz broadcast audio channel to a 512 kb/s data channel, can be accommodated to serve both radio and data networks. Very small antennas, high availability (up to 99.99%), and highly integrated electronics, make fm³ technology ideal for every broadcast network.

In a typical network, the data or audio to be broadcast is sent to the Chicago International Teleport using dedicated phone lines, fiber optic lines or SCPC technology. At the Chicago Teleport, the data or audio is received, modulated using fm³ technology, and broadcast over Ku-band capacity on the Galaxy IV-H satellite.

SCPC Transmissions

Audio subcarriers and sound-in-sync transmissions always are linked to the video waveform. However, *single channel per carrier* (SCPC) signals can have their own independent carriers and frequency assignments within the bandwidth of a given transponder. Either analog or digital modulation techniques can superimpose the audio or data information onto the SCPC carrier. Because of the relatively narrow bandwidth of each SCPC transmission, a single satellite transponder conceivably can contain hundreds of individual audio signals. The amount of bandwidth actually occupied by any SCPC signal depends on how much the SCPC carrier is *deviated*—shifted from the main carrier frequency—by the *modulating* audio signal. (Modulation means impressing information upon a carrier wave by varying some parameter of the wave.)

FM-modulated voice signals typically have a bandwidth of 25 to 45 kHz, while broadcast quality audio program distribution requires a bandwidth of 100 to 250 kHz. Digitally modulated SCPC signals for *thin-route* (low density traffic) voice applications or data transmissions ordinarily use 30 to 60 kHz of bandwidth per signal. Broadcast-quality audio ordinarily requires a bandwidth of 100 to 250 kHz.

High fidelity SCPC channels use more bandwidth because of the higher FM deviation level required to faithfully reproduce the entire spectrum of audio frequencies (50 Hz to 15,000 Hz) used for most musical compositions. SCPC telephone traffic requires a lower level of deviation because it only reproduces the human voice (50 Hz to 3,000 Hz).

Compander circuits often are used to compress the extreme peak deviation levels of the audio or data signal before they are modulated. This permits the maximum number of voice and data signals to occupy a transponder. Receiving earth stations use an inverse gain expander circuit to return the compressed signals to their original state.

SCPC Services

Single Channel Per Carrier (SCPC) services transmitted by North American domestic satellites include many national, regional, and state radio networks, unedited news and sports feeds, foreign-language services, and religious radio networks. International satellites use SCPC transmission techniques to relay radio programming, the sound portion of certain TV broadcasts, and a multiplicity of two-way telephone conversations.

INTELSAT uses two SCPC methods for video relays. The first of these is the *half-transponder* method. A transponder is divided into two separate halves, with the video programming occupying one half, and many SCPC signals in the other half. One of these half-transponder SCPC transmissions will include the audio for the video on the other half of the transponder.

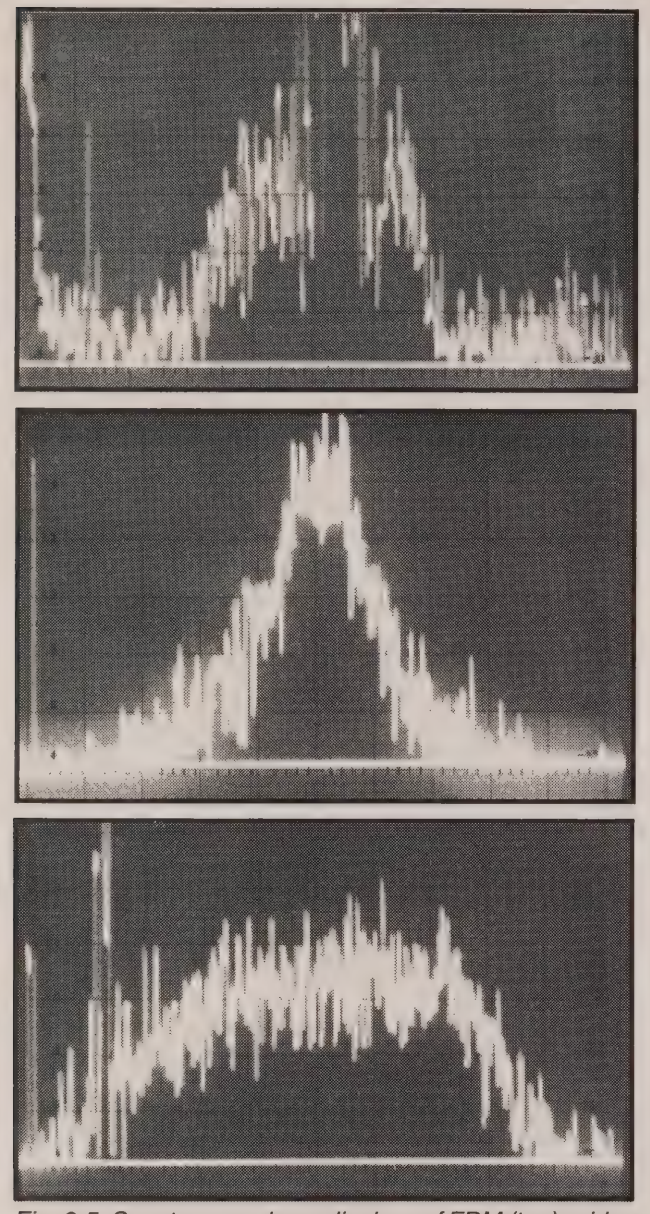


Fig. 6-5. Spectrum analyzer displays of FDM (top), video (center) and a wideband digital (bottom) signals.

Other SCPC transmissions may include separate radio station broadcasts, telephone conversations, and special marker signals called *pilot tones.* Several developing countries use the half-transponder method to squeeze the most use out of a single transponder.

The second method used to combine video and SCPC signals uses two totally separate transponders. The SCPC sound circuit for the video service transmits on one transponder, the video on another.

Experimental Data and Audio Reception

by Thomas P. Harrington

For more than 40 years, Thomas P. Harrington has been actively involved in the evolution of radio communications. He is responsible for several technical developments that are widely used in the field of space communications. A lifetime member of the American Radio Relay League (W8OMV), Tom is well known for his numerous magazine articles and books covering radioteletype (RTTY) and other data transmission systems. Tom also is the author of ***Hidden Signals on Satellite TV,*** *a standard reference covering the mechanics of receiving satellite voice and data signals.*

There are several experimental systems that will allow reception of voice and data transmissions. These systems make use of standard simple equipment that is available at reasonable prices.

The heart of all of the outlined systems is, of course, a working dish measuring 7.5 to 10 feet in diameter, with a proper actuating system to move the dish through the geostationary arc. An LNA or LNB can be used depending on the block of frequencies you select to work with.

The standard LNB used in today's TVRO systems will yield a block of frequencies from 950 MHz to 1450 MHz from the standard downlink frequencies of 3.7 GHz to 4.2 GHz satellite signals. The old 70 MHz downconverters also could be used in experimental data and voice reception systems providing the downconverter is stable or can be made stable by providing a constant temperature environment. When using one of the older downconverters with a 70 MHz intermediate frequency (IF) output, the operator will tune a spectrum that ranges from 50 MHz to 90 MHz on the receivers listed in this section.

Satellite Voice Systems (SSB/FDM)

Satellite capacity is huge. We talk about a transponder being 36 MHz wide, little realizing that this spectrum could accommodate 3,600 evenly spaced 10 kHz wide standard AM broadcast stations.

In the single side band (SSB) mode with 4 kHz channels, we could stack 9,000 of these SSB signals in the same space used by one transponder 36 MHz wide (SSB/FDM).

For voice reception, we will use a quality continuous coverage communications receiver with a frequency range of 100 to 3,000 kHz (.1 to 30 MHz) with single sideband modes. The following receivers will work very well: Kenwood R-2000, R-5000, Icom R-71A, R-1000 or any amateur band transceiver that tunes from 100 kHz to 30 MHz.

Fig. 6-7 shows the basic hook up of the communications receiver to the satellite receiver. The satellite receiver must have an unclamped baseband output of 0 to 13 MHz. Many satellite receivers have a built-in filtering circuit that passes only the portion of baseband that is going to contain video information. The cross-over point can occur any place from 4.2 to 4.5 MHz. That means that anything above this filtering point is going to get "chopped" out of the baseband output and will be severely attenuated or eliminated. The best solution is to look for a point in your satellite receiver at which you can connect an output coax connector ahead of the filter.

After you locate the spot ahead of the filter, connect an .001 disc ceramic capacitor from that point to a new (added) "F" output connector. Use a coaxial cable to attach this point to the antenna input of the communications receiver.

If the satellite receiver is putting too much signal into the communications receiver, simply switch the communication receiver's attenuator, which, in many cases, will offer attenuation in 10 dB steps. Please note that on some of the older satellite receivers, the units may have a true unfiltered baseband output marked as such; in other cases, this output is called a descrambling outlet. Most late model satellite receivers will provide a true unfiltered baseband output connection.

Tuning the Group of Signals

As you tune between 100 kHz and the top end of the band, you may notice that suddenly a whole group of signals can't be tuned in or *clarified.* Don't panic—the uplink transmitter has simply multiplexed this group or supergroup into the circuit "upside down." To tune them in, switch the communications receiver from a lower sideband to upper sideband.

Fig.6-6. Language to describe various satellite and communications modes.

(A) SINGLE SIDEBAND TYPE - DATA - FAX - MPX: SSB/SCPC
(B) FM FORMAT TYPE - DATA - MPX; FM/SCPC
(C) TELETEXT ON A SUBCARRIER: TxT/SC
(D) TELETEXT ON VERTICAL BLANKING INTERVAL: TxT/VBI
(E) DIGITAL MODULATION: DM/SCPC
(F) SLOW SCAN TV IN VERTICAL BLANKING INTERVAL: SSTV/VBI
(G) SPREAD SPECTRUM: SpS
(H) SUBCARRIER USE: SbC/FM
(I) FACSIMILE, CRT-VIDEO OR HARD COPY: FAX
(J) MULTIPLEXING: MPX

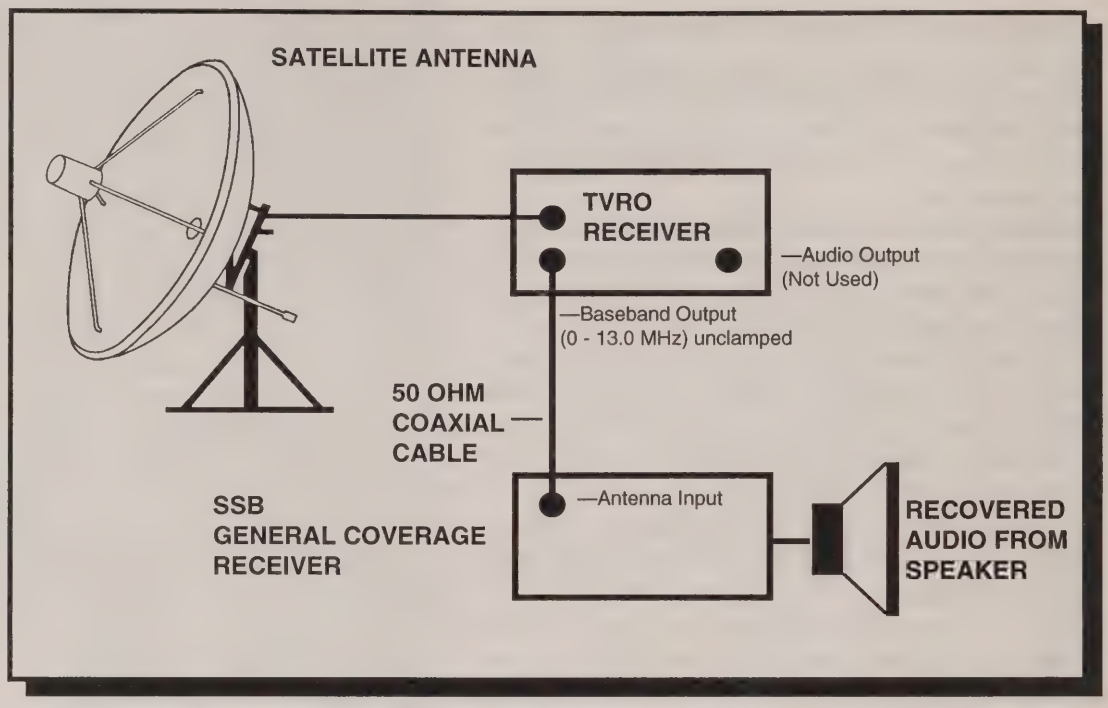


Fig.6-7. Basic hook-up of SSB Receiver to satellite Receiver for voice reception of SSB/FDM.

Single sideband frequency voice systems (SSB/FDM) will use a basic 4 kHz wide channel. There are 12 channels to one audio group, 5 audio groups make one super group; 5 supergroups make one mastergroup.

At this point you must learn to tune the communications receiver in the single sideband mode in order to receive a clear signal. The commercial channels seem to be carried in groups within a transponder. When you find one, you usually will find another good channel nearby. These channels will be grouped with the telephone channels as all are SSB/FDM signals. When a series of telephone channels are grouped together, one channel usually will be using the upper sideband and the one next to it will be using the lower sideband. Therefore, it is necessary to change the receiver's sideband control to select the proper sideband before copying these signals.

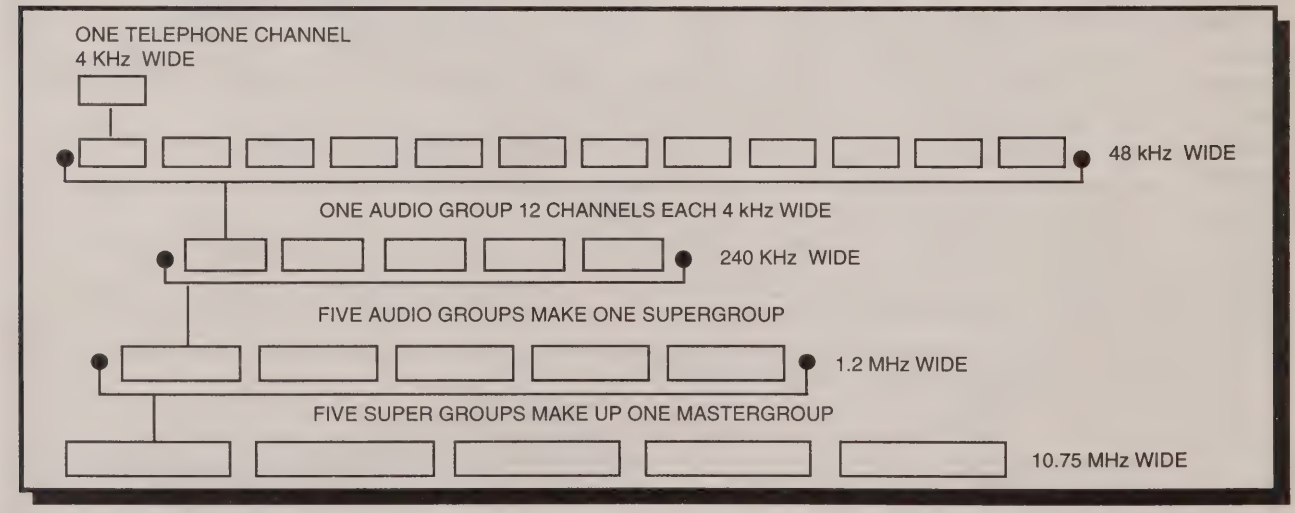

ONE TELEPHONE CHANNEL
4 KHz WIDE
48 kHz WIDE
ONE AUDIO GROUP 12 CHANNELS EACH 4 kHz WIDE
240 KHz WIDE
FIVE AUDIO GROUPS MAKE ONE SUPERGROUP
1.2 MHz WIDE
FIVE SUPER GROUPS MAKE UP ONE MASTERGROUP
10.75 MHz WIDE

Fig.6-8. Basic multiplexing telephone system used on many satellite systems (single side band multiplexing mode).

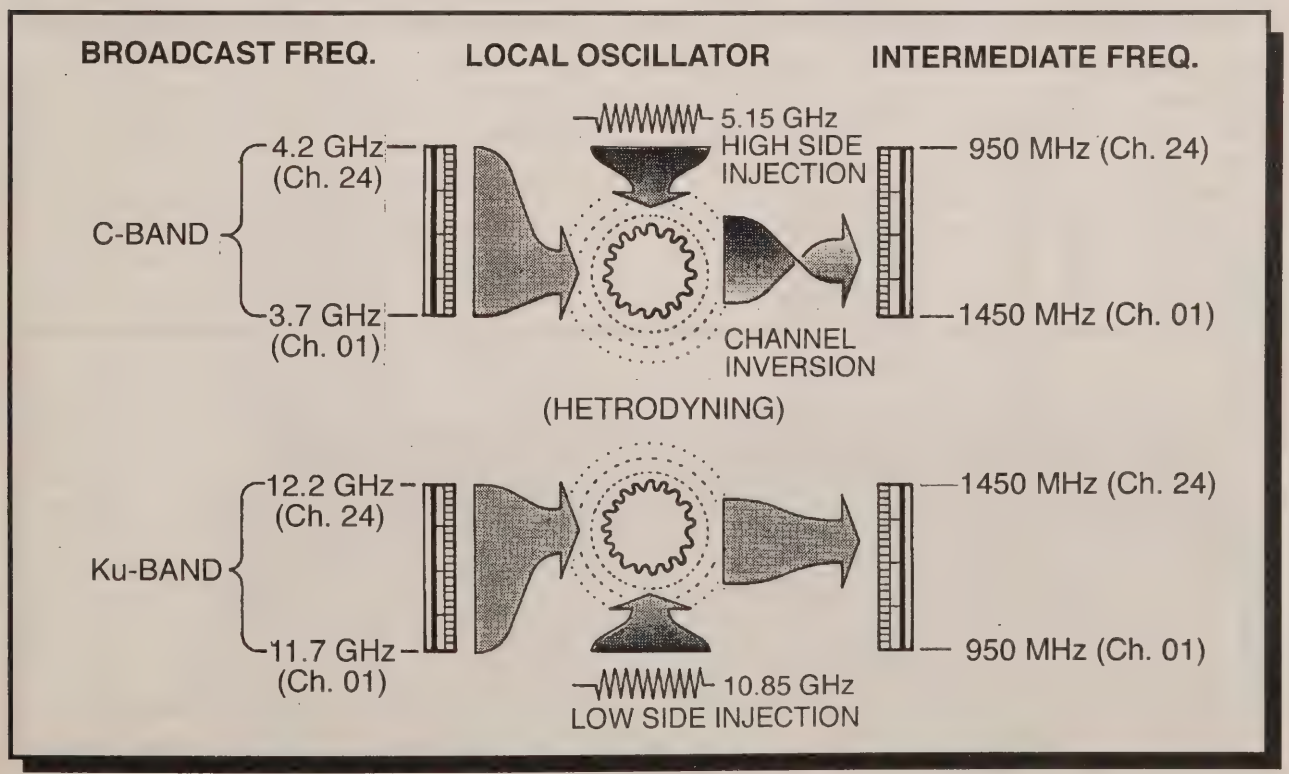
Single Channel Per Carrier (FM/SCPC) (SSB/SCPC)

There always has been two separate methods of transmitting narrow band material via satellite. In 1980, one of these formats (SSB/SCPC) predominated, while the technically superior and more complex FM/SCPC mode was a newcomer. In the interim years, the FM system has taken hold and most of the high quality audio and data links in use today, on both domestic and INTELSAT satellites, rely on this frequency modulation system.

The development of radio networks in the late 20s and early 30s provided the foundation for North America's modern-day broadcasting industry. Radio networking depended for years on the Bell Telephone company's land line and microwave systems for interconnecting affiliated radio stations with the networks. Bell always has been "network quality line" limited as the circuit typically is capable of passing audio only in the 50 Hz to 3000 Hz region with good clarity. Therefore, these circuits have had to be specially "equalized" using equipment which is dedicated to broadcast circuit use.

It was a natural, then, for radio networks to look with favor on the establishment of satellite linked interconnection systems. These systems are capable of handling all of the audio range required (20 Hz to 20,000 Hz) and can handle added circuits needed to give the stations the flexibility they need to do a better job.

Fig. 6-9. Following amplification of the incoming signals, the low noise block downconverter (LNB) transforms the entire incoming satellite frequency band down to a lower 500-MHz-wide (750 MHz or even wider for many European Ku-band LNBs) block of intermediate frequencies that contain all satellite signals of a given polarization.
C-band LNBs with an output range of 950 to 1450 MHz use what is called a high-side oscillator of 5.15 GHz, a signal that is higher in frequency than the one being received. One result of heterodyning the high side oscillator frequency with the incoming 4 GHz signals is that the resulting IF block is turned inside out or inverted. Signals contained within transponder 1 (3720 MHz) at the low end of the C-band will appear at the upper end of the IF block of frequencies (1430 MHz). This must be kept in mind when using an SCPC receiver that taps into the 950 to 1450 MHz IF range. Ku-band signals are not inverted, i.e., 11.720 GHz will appear at the lower end of the Block IF band (970 MHz).



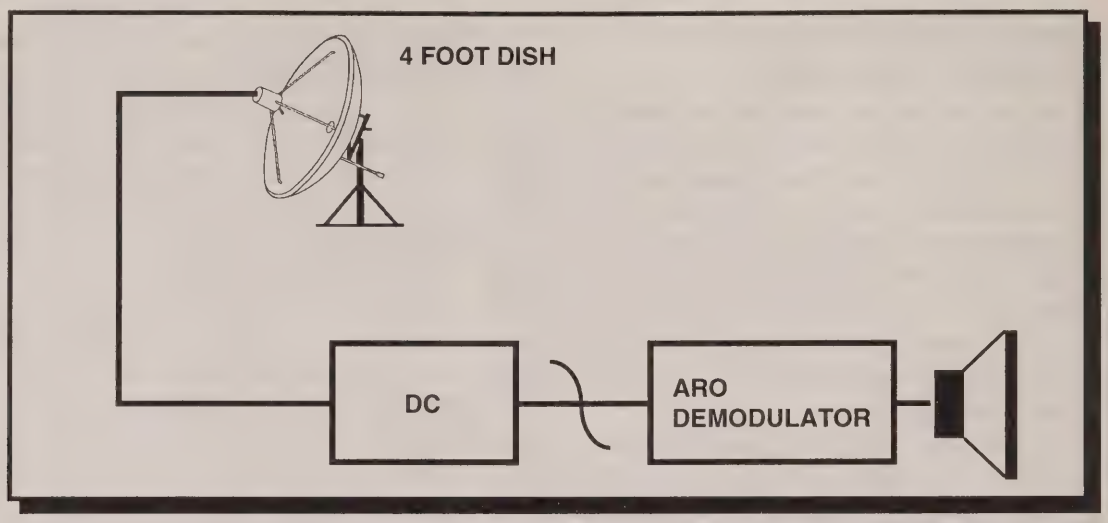


Fig.6-10. Dedicated 4 foot ARO dish offers quality FM/SCPC service with small dish.

Satellite links can be "stacked" with two or more channels for a minimal increase in cost.

The basic ARO (audio/receive only) terminal consists of an antenna, LNA (low noise amplifier) and downconverter or a LNB (low noise block downconverter) and a ARO demodulator.

There are quasi standards in this field; the most frequently utilized standards place the individual audio and data signals inside of a transponder at 200 kHz intervals. Individual "channels" occupy a bandwidth of 60 kHz (see Fig. 6-11 below). If the transponder carries no video, then the entire transponder can be divided into a subworld all to itself.

The basic experimental SCPC system shown in figure 6-12 uses the Icom R-7000 receiver as the demodulator for the system. After completing all necessary connections, follow these simple steps:

1. Caution—do not input D.C. voltage from

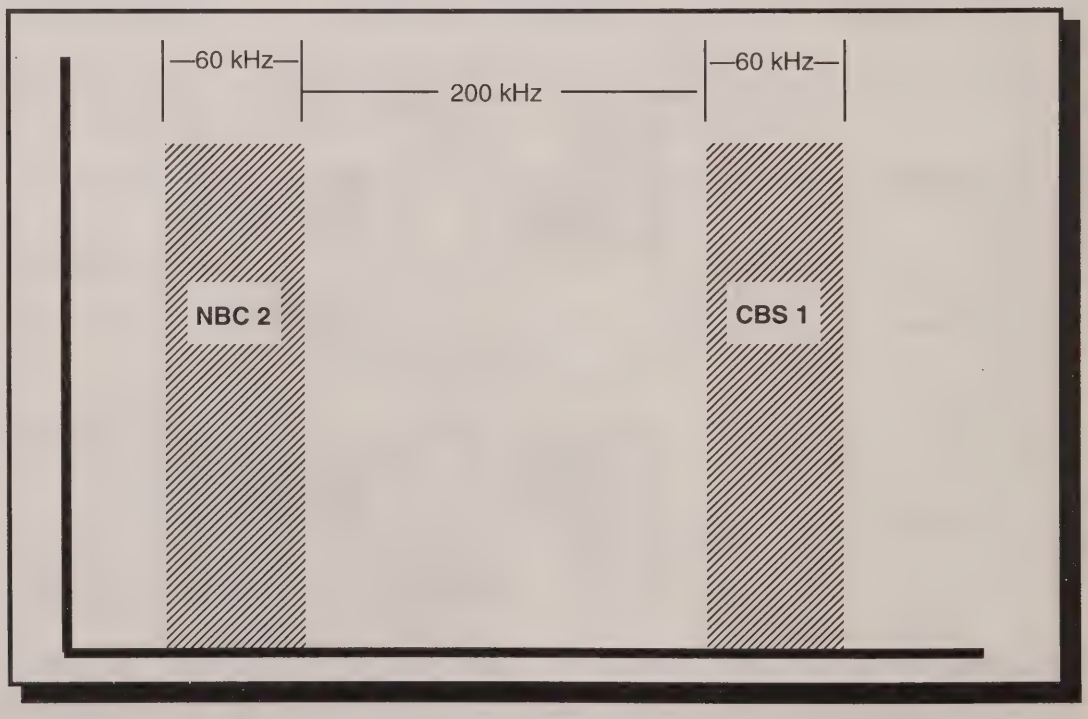


Fig.6-11. FM/SCPC services can be found spaced, typically, 200 kHz apart (center to center) with each 60 kHz wide.

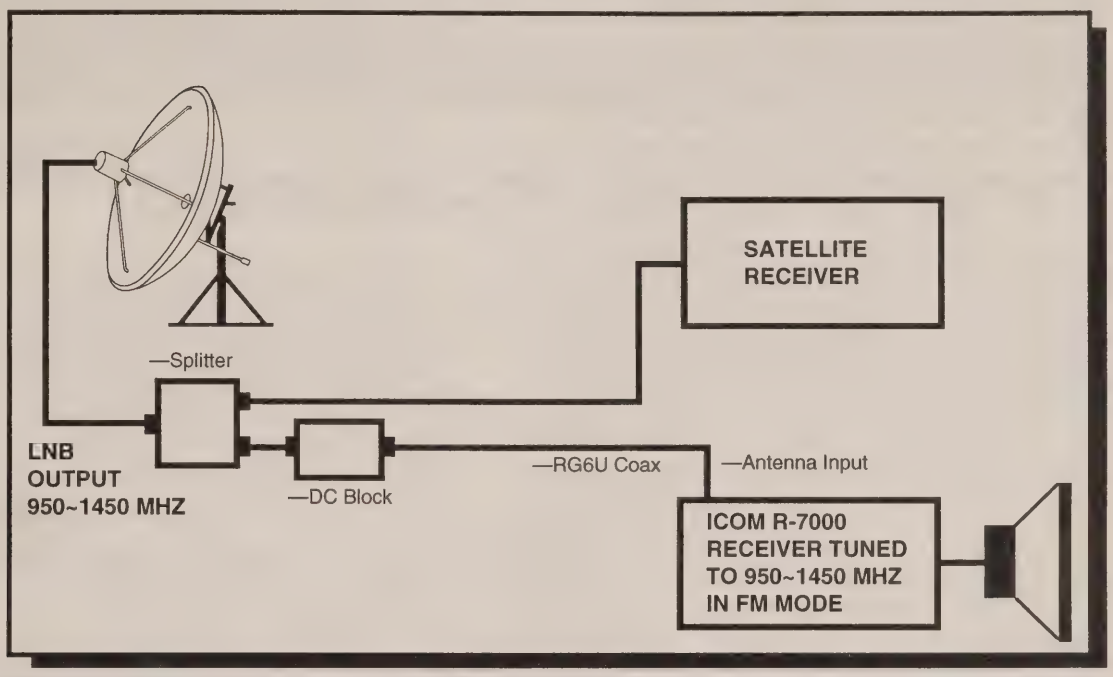


Fig.6-12. SCPC system with LNB output of 950 - 1450 MHz splitter (Radio Shack 15-1141) 75 ohm, DC block.

the LNB into the antenna input of the R-7000 as this will damage the receiver. Use a DC block from the splitter output going to the receiver.

2. Program the R-7000 to start tuning at 950 MHz and continue to tune the entire block up to 1450 MHz.

3. Place the R-7000 in the FM mode, try narrow FM or wide FM for best reception of each SCPC signal.

4. Tune through the entire 950 to 1450 MHz IF frequency range in first one and then the other sense of polarity for full coverage of all SCPC channels.

Automatic Transmitter Identification System (ATIS)

The U.S. Federal Communications Commission requires all uplink satellite broadcasters to place a Morse Code (CW) identifier on their uplinked signal to indicate the origin of the programming. The identifier helps other stations identify possible sources of interference to their own satellite operations.

The ATIS message usually is carried on a 7.10 MHz subcarrier; some B-MAC encrypted signals, however, use an 8.30 MHz subcarrier. The ATIS message is transmitted in Morse Code at a speed of about 25 words per minute

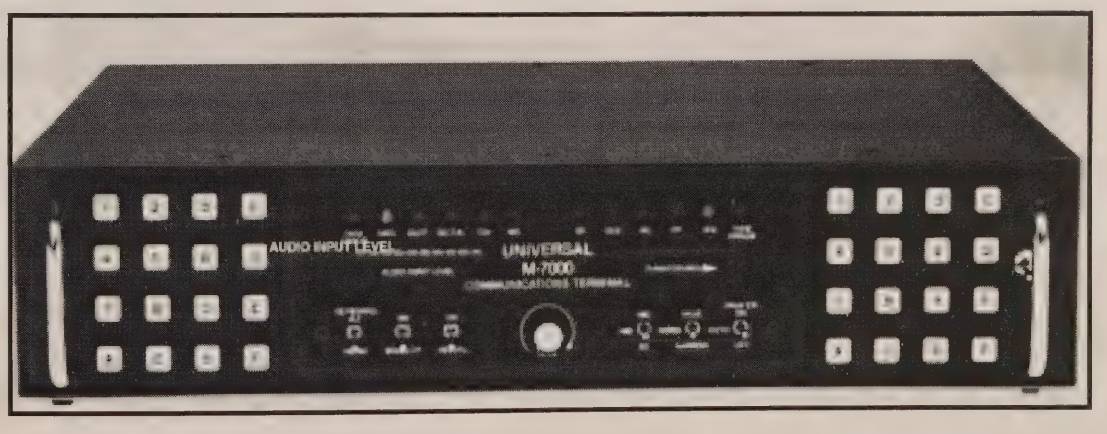


Fig.6-13. Universal M-7000 Communications Terminal for decoding the ATIS signals on some U.S. satellite subcarriers, plus other communications modes.

(WPM). The ATIS message carries the call sign (E followed by a string of four or more numbers), a special identity code, the uplink telephone number, plus other information.

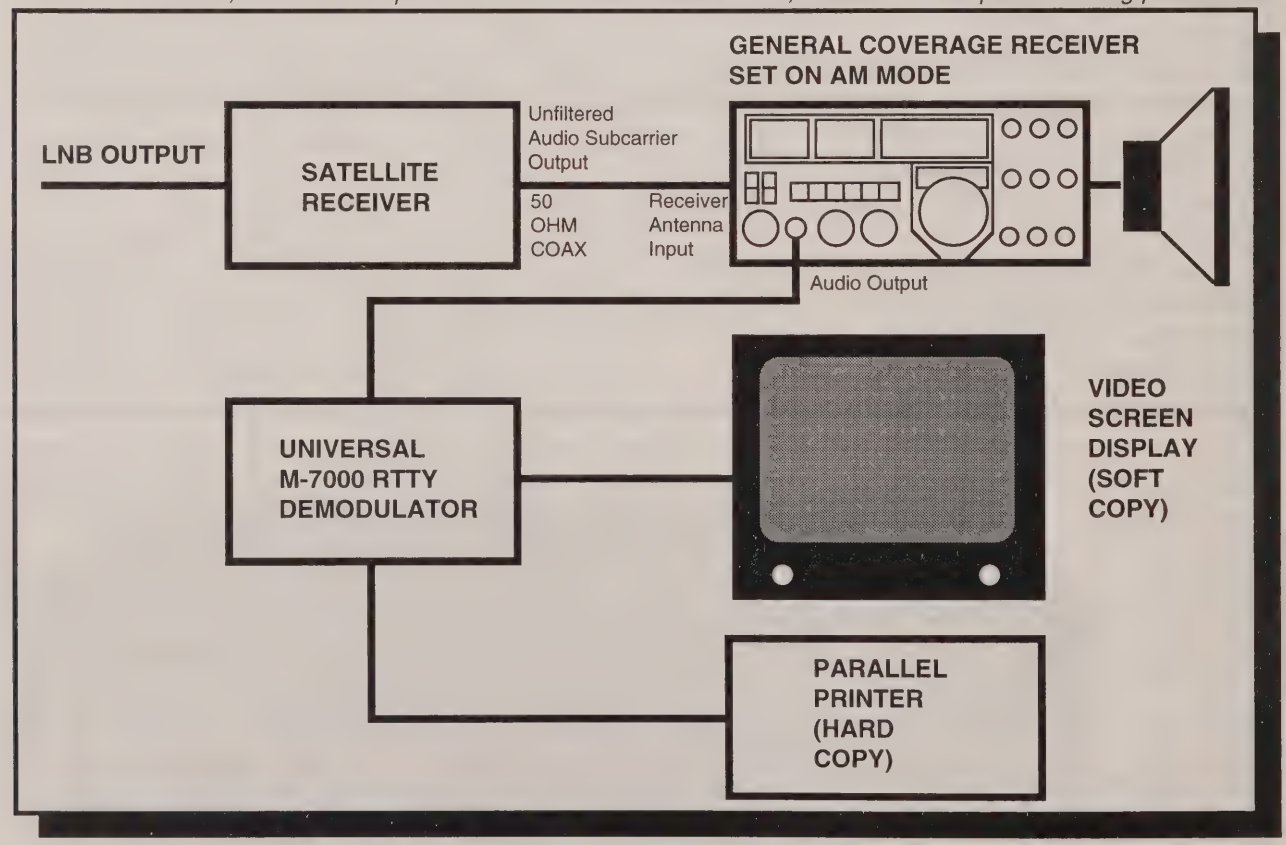
There are several ways to decode these ATIS messages. The first way is to become proficient in the copy of Morse Code. The other is an automatic decoding system that uses the Universal M-7000 decoder, a unit that will decode all speeds of Morse Code plus many other standard low baud rate communication codes used for satellite and terrestrial services.

Some of the reception modes of the Universal M-7000 unit are: Morse Code to 120 WPM, Baudot, ASCII, Sitor A and B, VFT, ARQ Moore, ARQ-E, ARQ-E2, packet, facsimile, and Russian, 3rd shift Cyrillic. The M-7000 is a microprocessor-controlled stand-alone unit that will decode and furnish soft copy (video) or hard copy output—no computer is needed. The simple system using the M-7000 was shown earlier (in Fig. 6-12). 52 Ohm coax is used in the connection from satellite receiver to the antenna input on the general coverage receiver. The audio out from the general coverage receiver to the Universal M-7000 RTTY demod is common audio cable.

Data Transmissions on SCPC Channels

It is possible to expand the SCPC system by linking the audio output of the R-7000 receiver to the audio input of the Universal M-7000 demod unit. A common audio cable with proper connectors at each end is used to transport the audio signal between the two units. At this point, the SCPC signals will have to be identified as to the code being used on any particular channel. Set the M-7000 unit to the proper code to obtain clear copy.

Fig.6-14. Use of HF general coverage receiver for accurate subcarrier tuning. HF receiver must have a range of 100 kHz to 30 MHz, all mode reception. M-7000 unit will be set for cw, Morse Code as per the tuning procedure.



Chapter 7

Satellite TV Receive Only (TVRO) Systems

The first step to choosing the best satellite TV components for any location is to obtain an accurate reading of satellite signal levels. Then carefully consider the operational characteristics of the domestic and international satellites visible from the site location. It is especially important to note the audio and video transmission parameters.

Satellite Earth Station Antennas

The antenna is the most important component of any satellite TV system. Receiving international satellites often requires an antenna greater than 16 feet (5m) in diameter. Receiving domestic satellites usually requires an antenna diameter of less than 12 feet (3.6m) for C-band systems or 3.28 feet (1m) for Ku-band systems. Receiving high-power DBS satellites usually requires an antenna two feet (60cm) in diameter or smaller.

One way to improve the performance of any receiving system is to increase the size of the antenna. Doubling the surface area of a dish results in a 3 dB improvement in signal level. This is exactly what would happen if we were to substitute a 20-foot (6m) antenna for a 13-footer (4m). (The surface area of an antenna is not proportionate to its diameter.) Unfortunately, doubling the antenna surface area is an expensive proposition.

Parabolic Antenna Geometry

Most satellite antennas are passive reflectors with a design that is based on the curvature of a parabola. The parabola is that curve for which all incident rays parallel to its axis of symmetry are reflected to a point on the axis. This point is known as the focal point, or focus, and the distance from the focus to the longest point of the parabola is called the focal length. The direction of the rays is reversible, i.e., the radiation from a point source at the focus is reflected outward as a parallel beam. A reflective parabola of revolution, that is, a surface having the shape of a parabola rotated about its symmetry axis, shares the property of optical lenses, being able to form an image of whatever object is placed in front of it.

The largest optical and radio telescopes use parabolic reflectors to gather and concentrate radiation. The formation of high-resolution images depends upon the requirement that the maximum antenna surface irregularity and/or departure from the parabolic shape be less than about 1/4 to 1/2 of the radiation's wavelength.

A practical example is a mesh reflector dish for satellite TV reception; as long as the holes and bumps of the mesh are significantly less than the wavelength of the signal (1.5cm or less

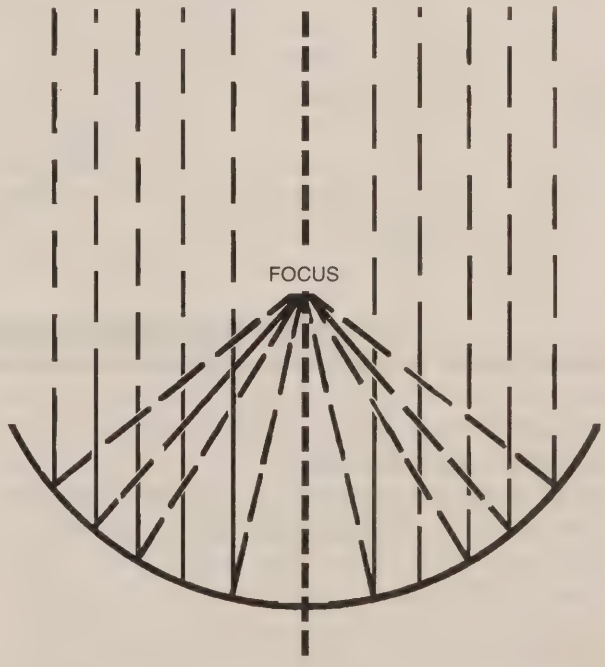


Fig.7-1. The parabola is that curve for which all incident rays parallel to its axis of symmetry are reflected to a point on the axis.

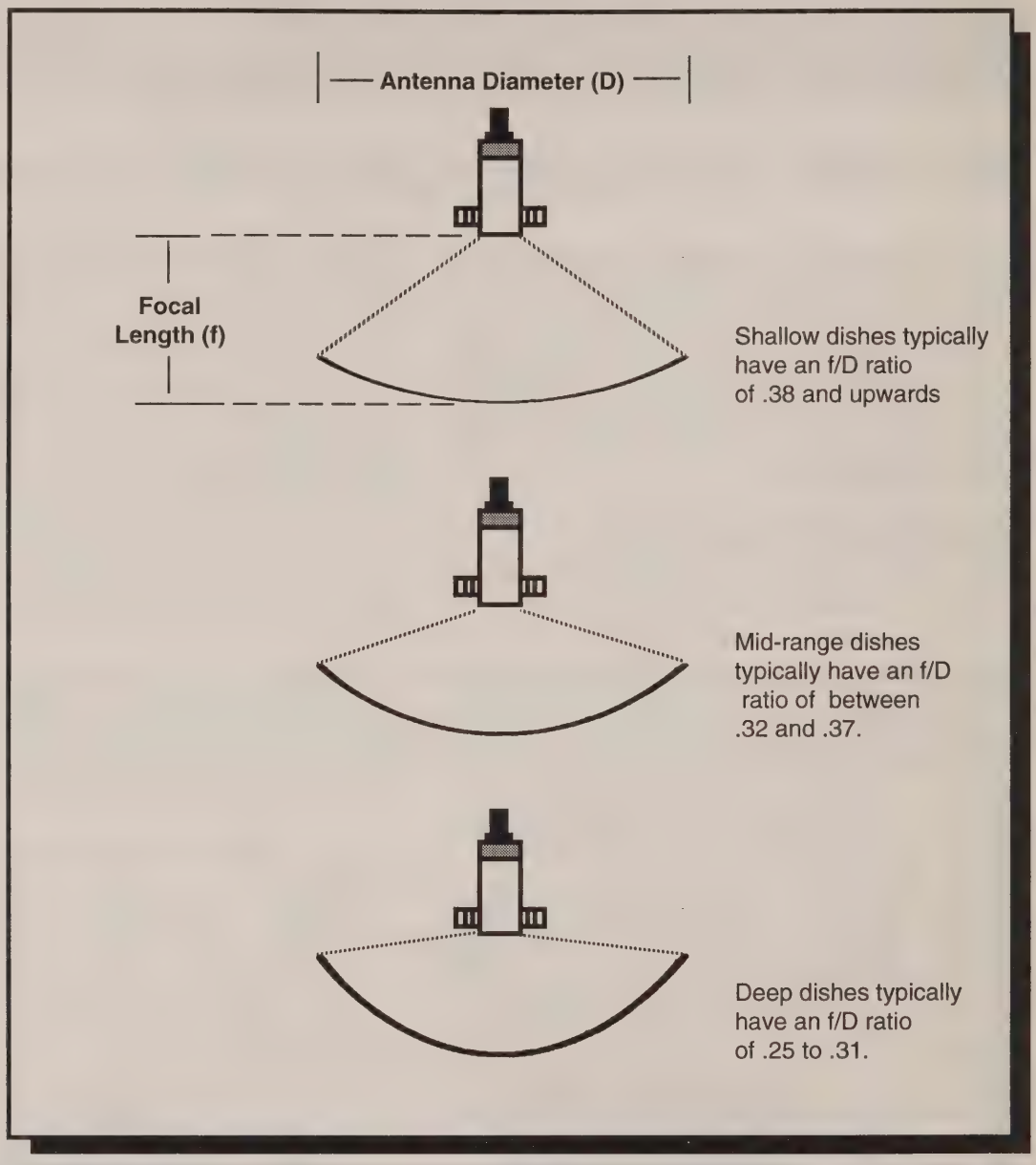

Antenna Diameter (D)
Focal Length (f)
Shallow dishes typically have an f/D ratio of .38 and upwards
Mid-range dishes typically have an f/D ratio of between .32 and .37.
Deep dishes typically have an f/D ratio of .25 to .31.

Fig.7-2. Focal length to antenna diameter (f/D) ratios.

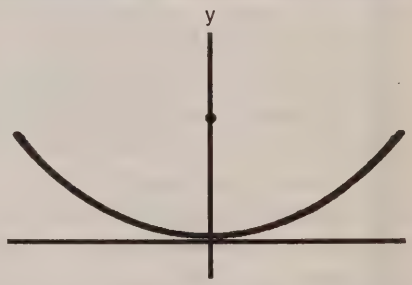
at 4 GHz), the mesh dish "looks" like a smooth mirror to the radiation.

The parabolic curve in two dimensions can be represented analytically by the equation:

$$y = \frac{x^2}{4f}$$

An equally valid representation of the curve would be simply a tabulation of the coordinates of several points on the curve:

x	y
0	0
1	1/4f
2	1/f
f	f/4
2f	f



and so on. Notice that you are free to choose the parameter f, which happens to be the focal length on the y axis.

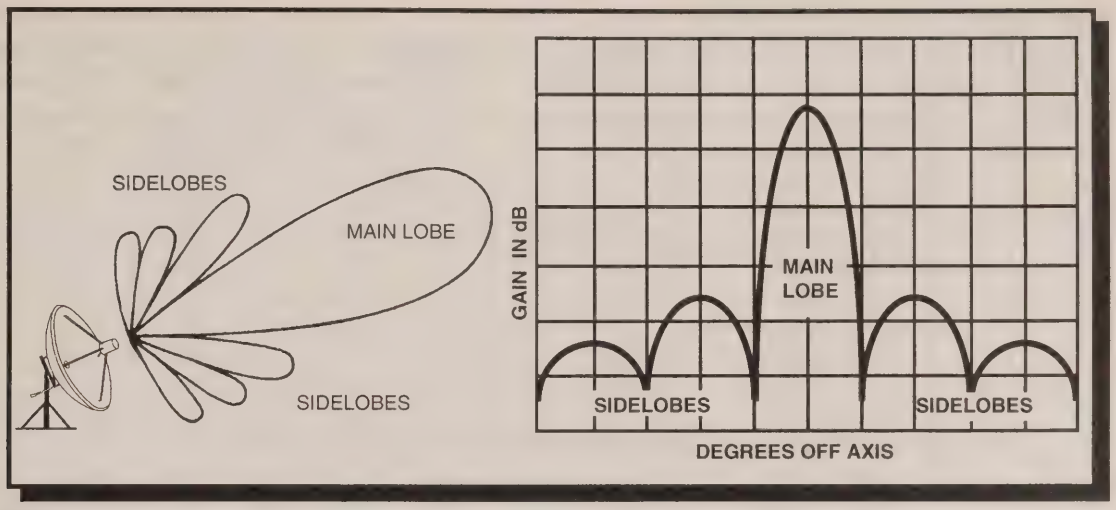


Fig.7-3. Antenna sidelobes and ideal radiation pattern.

Antennas with a focal length to antenna diameter (f/D) ratio ranging from .25 to about .31 are generally referred to as *deep dishes* while reflectors with an f/D ratio of between about .375 and .45 are considered to be *shallow*. With a deep dish design, the feedhorn and amplifier are positioned relatively close to the surface of the antenna, sometimes at a level that is almost parallel with the rim of the dish. Shallow dishes, on the other hand, position the feedhorn and LNA so that it sits at a further distance from the center portion of the reflector surface.

The ultimate satellite receiving antenna would provide infinite gain to signals entering the boresight—the narrow corridor located to the front and center of the dish—while providing no gain to signals striking the reflector surface from other angles. While no such antenna exists in the material world, antenna designers do attempt to maximize the amplification at boresight while minimizing the gain of signals or noise coming from other directions.

During testing, engineers generate an antenna radiation pattern that graphically illustrates the gain performance of the parabolic reflector. A typical antenna gain plot identifies the level of amplification provided by the *main lobe* of the pattern. The main lobe of any antenna's radiation pattern has a "beamwidth" that is measured in degrees. The half power beamwidth of an antenna's main lobe is expressed as the number of degrees from the main beam's axis at which the signal power level drops by 3 dB. All other factors being equal, the beamwidth of a parabolic antenna decreases as the antenna aperture and/or the operating frequency increases.

Antenna patterns also can reveal multiple *sidelobes* which lie several degrees off the axis of the antenna's boresight. Since these sidelobes also have gain, they can amplify signals coming from adjacent satellites which may fall within the sidelobe's axis, causing interference to signals emanating from the preferred satellite. To combat potential interference problems, sidelobe gain must be significantly lower—from approxiamtely -16 to -21 or more dBi—than the gain provided by the main lobe. Low side lobe levels are an indication of good surface curvature accuracy and the proper match of the feedhorn to the antenna.

Antenna Efficiency

Two antennas may present an identical aperture for the incoming satellite signals, but one antenna may exhibit a greater ability for actually using all of the signal striking its surface. The efficiency rating of an antenna quantifies that portion of the signal striking the antenna surface which actually arrives at the focal point. Antenna efficiency is expressed as a percentage and primarily is determined by the accuracy of the parabolic reflector's surface curvature. Antenna efficiency ranges from about 55 to 75 percent.

The calculations used to prepare the C- and

Fig.7-4. C- & Ku-band Antenna Gain/Efficiency Chart.

	C-band 3.7~4.2 GHz		European[1] FSS Ku-band		American[2] FSS Ku-band		Asia/Australia[3] FSS Ku-band	
Efficiency:	55%	70%	55%	70%	55%	70%	55%	70%
1 ft. (.30m)	19.4	20.5	28.5	29.6	29.0	30.1	29.4	30.4
2 ft. (.61m)	25.4	26.5	34.6	35.6	35.1	36.1	35.4	36.5
3 ft. (.91m)	29.0	30.0	38.1	39.2	38.6	39.6	38.9	40.0
4 ft. (1.22m)	31.5	32.5	40.2	41.7	40.7	42.1	41.4	42.5
5 ft. (1.52m)	33.4	34.4	42.5	43.6	43.0	44.1	43.4	44.4
6 ft. (1.82m)	35.0	36.0	44.1	45.2	44.6	45.6	45.0	46.0
7 ft. (2.13m)	36.3	37.4	45.5	46.5	45.9	47.0	46.3	47.3
8 ft. (2.43m)	37.5	38.5	46.6	47.7	47.1	48.1	47.4	48.5
9 ft. (2.74m)	38.5	39.5	47.7	48.7	48.1	49.2	48.5	49.5
10 ft. (3.05m)	39.4	40.5	48.6	49.6	49.0	50.1	49.4	50.4
11 ft. (3.35m)	40.2	41.3	49.4	50.4	49.9	50.9	50.2	51.3
12 ft. (3.65m)	41.0	42.0	50.1	51.2	50.6	51.7	50.9	52.0
13 ft. (3.96m)	41.7	42.7	50.8	51.9	51.3	52.4	51.7	52.7
16 ft. (4.87m)	43.5	44.5	52.6	53.7	53.1	54.1	53.5	54.5
20 ft. (6.09m)	45.4	46.5	54.6	55.6	55.1	56.1	55.4	56.5
25 ft. (7.62m)	47.4	48.4	56.5	57.6	57.0	58.0	57.3	58.4
33 ft. (10.05m)	49.8	50.8	58.9	59.9	59.4	60.4	59.8	60.8

(1) 10.950~11.700 GHz (Europe, Africa, and the Middle East; Palapa C & Measat in Asia.)
(2) 11.700~12.200 GHz (11.7 to 12.5 GHz High-power DBS band for Europe.)
(3) 12.25~12.75 GHz (12.2 to 12.7 GHz High-power DBS frequency assignment for the Americas.)

Ku-band earth station performance charts shown in the appendices assume a minimum antenna efficiency of 55 percent. However, many antennas available today achieve even higher levels of efficiency. When using a 70-percent-efficient antenna, for example, add +1 dB to the values presented in the appendices.

Antenna Gain

The antenna's *gain* rating quantifies its ability to amplify signals. Gain is measured in units of dBi or decibels referenced to an isotropic source—a theoretical antenna model developed by engineers which receives signals equally well from all directions at once. The isotropic source is assigned a gain rating of 0 dB.

Real-world antennas improve on the theoretical model by optimizing reception of signals coming from certain directions while minimizing signals arriving from other angles. Maximum signal levels are achieved by pointing the antenna directly at the desired satellite.

The gain of a parabolic antenna is directly related to its size, the frequency of the incoming signal, and the accuracy of the surface curvature. Generally speaking, the larger the capture area or *aperture* of the antenna, the greater the gain. The gain value also is directly proportional to the frequency of the incoming or outgoing signal.

Deviations in the surface accuracy of a portion of the reflector surface cause the reflected microwaves to be combined out of phase with the signal contributions made by other portions of the antenna. The result is a reduction in the overall gain of the antenna.

Antenna G/T

Antenna gain figures are not the final word on antenna performance. Even if an antenna exhibits high gain, its overall performance may suffer if it also has a high noise temperature. The real figure of merit for any earth station antenna is expressed as its G/T (pronounced

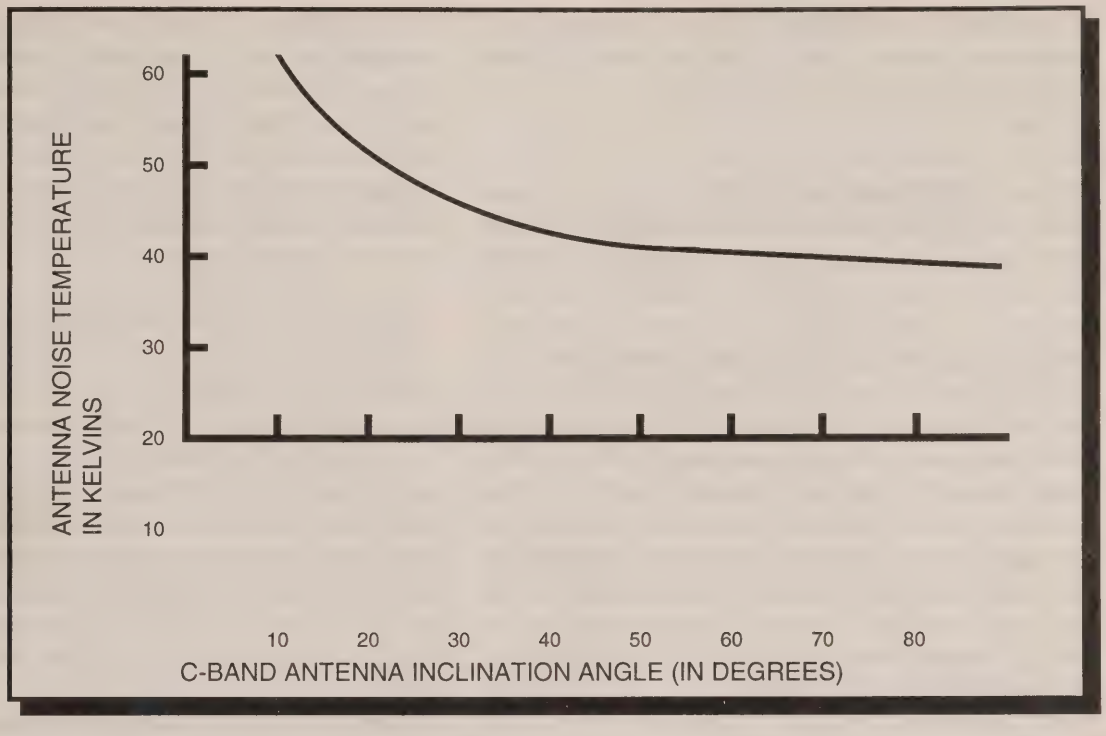


Fig.7-5. Antenna noise temperature chart.

"G over T"). The higher the G/T rating of an antenna, the better its performance. G/T is the ratio of antenna gain to antenna noise temperature. The noise temperature of an antenna depends on a number of factors, including antenna sidelobe performance, the elevation angle of the antenna when receiving a particular satellite and the f/D ratio of the antenna.

Antenna Noise and Free Space Loss

The C- and Ku-band earth station performance charts which appear in Appendix E can be used to determine the appropriate antenna aperture and efficiency (as well as other system requirements) for receiving any given satellite signal. These charts assume that the downward tilt or *inclination* angle (also referred to as the elevation angle) required for an antenna to receive any satellite is 25 degrees or more. Reception at any site location that requires an antenna inclination angle of less than 20 degrees will cause two problems.

At lower inclination angles, the antenna will intercept additional noise. The molecular action of the Earth generates random noise in the 4 GHz spectrum many times stronger than satellite signals. The antenna's sidelobes will intercept more and more of this thermal noise as the antenna progressively moves to lower inclination angles. This thermal noise raises the total noise temperature of the earth station system, degrading overall performance.

The antenna gain/efficiency chart provided on the previous page shows that a Ku-band receiving antenna with a given diameter would have approximately +9 dBi of gain over a C-band antenna with the same aperture and efficiency rating. This particular advantage is offset by *free space loss*—the weakening of the transmitted satellite signal as it travels from the spacecraft to the ground below—which is about 9 dB higher at Ku-band frequencies.

Satellites positioned to the extreme East or West of the site location will appear low on the horizon and will transmit over a longer distance than satellites which appear at higher points in the sky. Therefore the free space loss for these satellites will be greater.

Earth-generated noise and free space loss can be significant factors. As a general rule of thumb, subtract 1 dB from the performance charts in Appendix E for inclination angles from 11 to 20 degrees. For inclinations from 5 to 10 degrees, subtract 1.5 dB. The loss factor

for dish inclination angles lower than 5 degrees is much greater; reception at these angles usually is not recommended.

Antenna Mounts

One of the most overlooked aspects of any satellite antenna system is the mount. Due to the decreased beamwidth of Ku-band earth stations or large aperture C-band antennas, the mount must be rigid enough to maintain a precise position once it has acquired a satellite. Slight antenna movements of a fraction of an inch can make the difference between excellent reception and no reception at all. The mount must remain precisely pointed, even during bad weather conditions. The mount also acts as the main means of support for the parabolic reflector. Surface accuracy depends in part on the support that the mount gives to the antenna. Flexing can occur if the mount does not adequately distribute stress.

Polar Mounts

Polar mounts primarily are used by earth stations which commonly receive more than one communications satellite. These mounts track the satellites along the geostationary arc by means of a single adjustment in direction called the *azimuth*. Changes in the antenna's *elevation* angle automatically occur as the dish moves to the East or West. The polar mount has an axis that is parallel to the polar axis of the Earth. A single motor is used to pivot or rotate the antenna along this axis.

The plane of the polar axis also must be parallel to a line running from true North to true South. True North can be determined by adding or subtracting a correction factor from the magnetic North reading of a compass. Proper tracking of the Clarke Orbit also requires a precise declination setting. The declination for a polar mount varies depending on the latitude of the site location. Like the alignment of the polar axis to the true North/South line, the declination is initially set during the installation process.

Az/El Mounts

Az/El mounts commonly are used by earth stations that are dedicated to the reception of a single satellite. This mount has two independent adjustments: the azimuth and the elevation (inclination). There also are no declination and polar axis adjustments to complicate the installation process. Az/el mounts also can be motorized, but automatic control units for two motor drives are required.

Antenna Mount Limitations

Sometimes a site location requires a dish to tilt downward to a low inclination angle (sometimes called the minimum elevation angle by the antenna manufacturers) to receive a particular satellite which appears relatively low on the site's horizon. Always check with the manufacturer to make sure the antenna's mount can move to low inclination angles. Some dishes cannot move below 5 or 10 degrees in inclination, or may require special modifications to do so.

Single-stroke motorized actuators usually only can swing the antenna through approximately 70 degrees of the available arc. This may not be suitable for the intended purposes of the earth station operator.

For some sites, it may be essential to fit the dish with a motorized actuator system called a horizon-to-horizon drive. This type of drive can move the antenna through the portion of the geostationary arc that is visible from the site location.

When low antenna inclination angles are required to receive a given satellite or satellites, a deep dish generally will have less pronounced sidelobes than a shallow dish of equivalent diameter and therefore will intercept less ground noise.

Feedhorns and Polarizers

The parabolic curvature of the antenna reflects the satellite signals to a common point located to the front of the dish. At the *focal point*, the signals are collected by the feedhorn and sent on to the first stage of electronic amplification. Many feeds have a scalar plate consisting of a series of concentric rings that help to capture the incoming signals and direct them into the LNB's waveguide.

The Earth generates a noise temperature of 290 degrees Kelvin. The scalar rings act to taper the illumination efficiency of the feed so that the noise contribution of the ground just beyond the antenna's rim is minimized.

Feedhorns also are manufactured to deliver their best performance when matched to an antenna that has an f/D rating within a specific range of values. A mismatch of feed and antenna can result in substantial signal loss.

Prime Focus, Cassegrain and Offset Feeds

Efficiency also is determined by the location of the antenna's feedhorn and LNB. *Prime focus* antennas have a focal point located to the front and center of the antenna. The feed, LNB, and associated support structure are positioned in front of the antenna, thereby partially obstructing the path of the incoming signal.

Cassegrain antennas use a more complex feed arrangement which employs a hyperbolic subreflector at the front and center of the antenna. The subreflector bounces signals gathered by the antenna from the focal point back to the center of the dish, where a feed conducts the signal to an LNB located at the rear of the antenna. While Cassegrain antennas offer increased gain over their prime focus counterparts, they also present a partial obstruction to the incoming signal and consequently their sidelobe performance in a two-degree satellite spacing environment is generally not as good as that exhibited by a prime focus antenna.

Offset-fed antennas have a focal point that lies below the center of the dish. Since the feedhorn and LNB are positioned out of the way of the incoming signal, the antenna's radiation pattern is not distorted by any obstruction.

Offset-fed antennas are actually a smaller subsection of a much larger prime focus antenna. Because this subsection is oval in shape, with a minor axis that is narrower than the offset-fed antenna's major axis, the sidelobes generated by the antenna's radiation pattern are less pronounced. This reduces the amount of adjacent satellite interference received, and in the case of two-way VSAT terminals, transmitted by the offset-fed antenna.

If the parabolic curve of the offset-fed dish

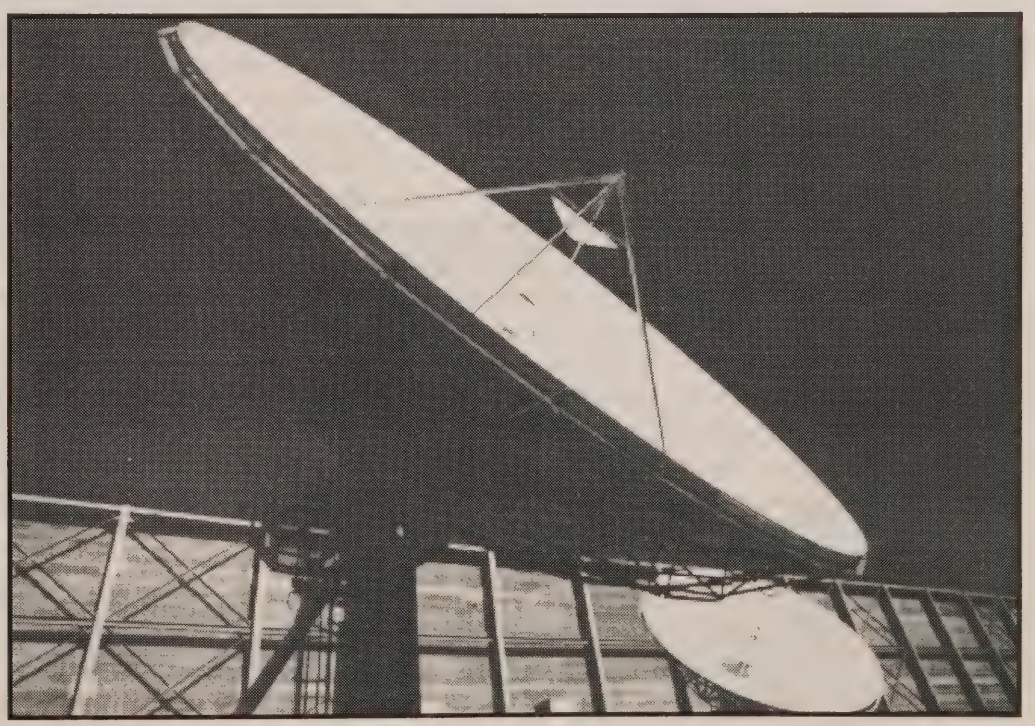


Fig.7-6. A cassegrain antenna with a hyperbolic subreflector. (Courtesy Comsat Corporation.)

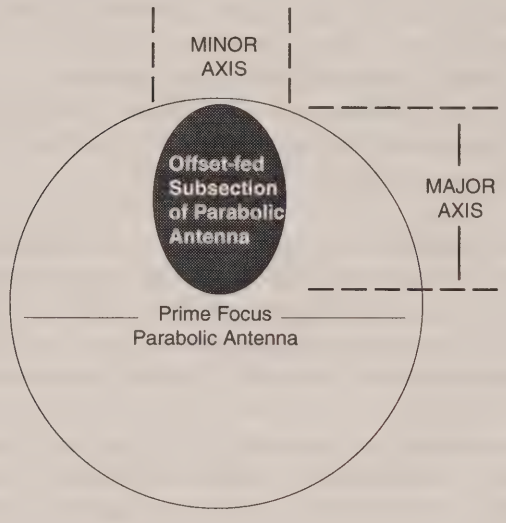


Fig. 7-7. Front view of parabolic antenna with offset subsection.

Fig. 7-8. An offset-fed parabolic antenna. (Courtesy Winegard).

was extended out to its full length, the focal point would actually be located to its front and center. The offset feed approach commonly is used by VSAT (very small aperture terminal) antenna designers because the lack of an obstruction to the incoming signals results in superior side lobe rejection.

Flat Antennas

Flat satellite antennas are now being produced for specific receiving applications. Two different basic designs are being used. One type of flat antenna uses the principle of a *fresnel lens*, which relies on the similarities between microwave energy and visible light. A circular pattern of slots cut into a flat piece of dielectric material can focus the incoming satellite signals onto a focal point which lies directly behind the lens. Alternatively, a flat section of metal can have circular slot patterns cut at angles into its surface so that the incoming microwaves are reflected to a focal point to the front and center of the plate.

The *planar array* uses an embedded gridwork of tiny resonant elements to receive the incoming satellite signals and concentrate them at a common point where the LNB is mounted. Because there is no signal reflection, planar array antennas do not require the use of a feedhorn or feed support structure. Although large C-band planar arrays have been built (as shown in Fig. 8-10), tested and demonstrated, this design approach is best suited for direct-to-home (DTH) satellite applications, where reception is confined to a single satellite or multiple collocated satellites.

The first prototypes of flat antennas for satellite communications applications were developed during the early 1980s at the engineering facilities of NHK Japan and several leading Japanese universities. Named after the shape of their individual elements, various "crank," "patch," and "slot" designs were examined for their positive and negative characteristics. All of these designs initially employed the same technology used to manufacture printed circuit boards, with the geometrical copper patterns etched onto the antenna's surface composed of

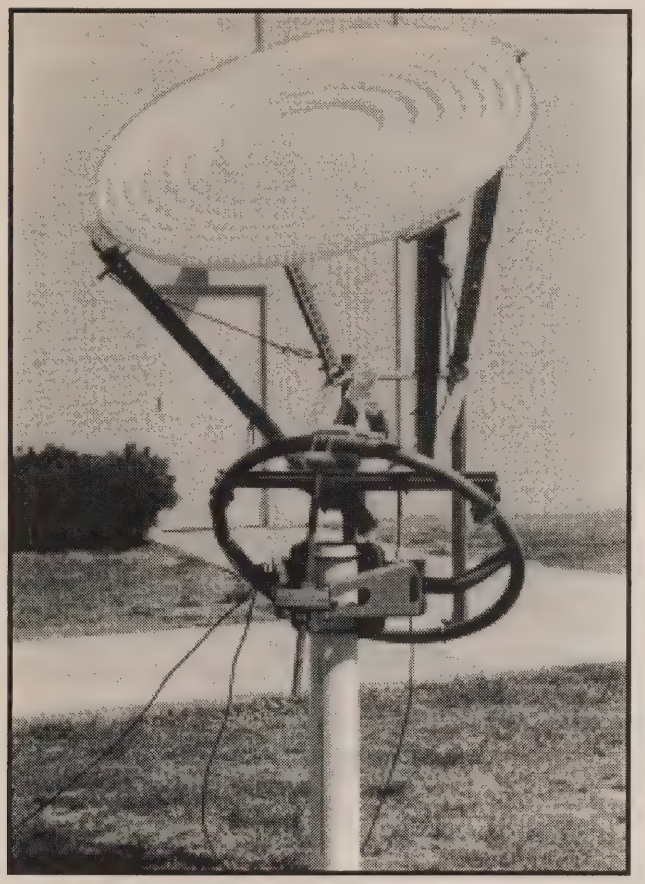


Fig. 7-9. Early prototype of a fresnel lens antenna using a dielectric developed by Harris Corporation. (Photo by Mark Long.)

tiny metallic elements. Through judicious selection of element dimensions, the engineers were able to tune the array to the appropriate frequency spectrums for satellite applications.

When the elements become excited by the presence of the incoming satellite signals, miniscule electrical impulses are generated within them which contain all characteristics of the original satellite signal. A gridwork of feeder lines link each element to a common output connector located at the rear of the antenna. All electrical currents generated within the array merge at this point, with the overall geometry of the array calculated to simultaneously combine all the individual electrical currents generated within the elements, thereby summing the many signals together.

More recently, design breakthroughs have been realized by Comsat Laboratories, Matsushita, and others, which have expanded the frequency bandwidth of flat plate antennas to permit their use over a wide range of frequencies. Moreover, improvements in antenna efficiency have been achieved which allow the flat plate antenna to perform at the same level as a parabolic antenna with an equivalent surface area. Finally, Comsat was able to substitute low-cost polyester films for the more expensive printed circuit boards used in the early flat plate prototypes. This made it possible for the flat plate antenna to achieve a price that is only marginally more than the cost of a dish of equivalent size.

The top layer or radome of the Comsat/Matsushita planar array (See Fig. 7-12) is a special protective surface material that seals out the environment while allowing incoming

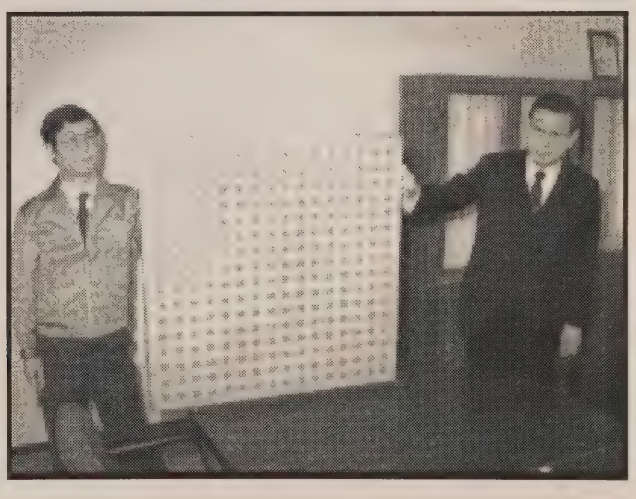


Fig. 7-10. Early prototype of a C-band planar array antenna developed by Uniden Corporation under the direction of Japanese DBS pioneer Dr. Yoshihiro Konishi shown at the right side of the picture. (Photo by Mark Long.)

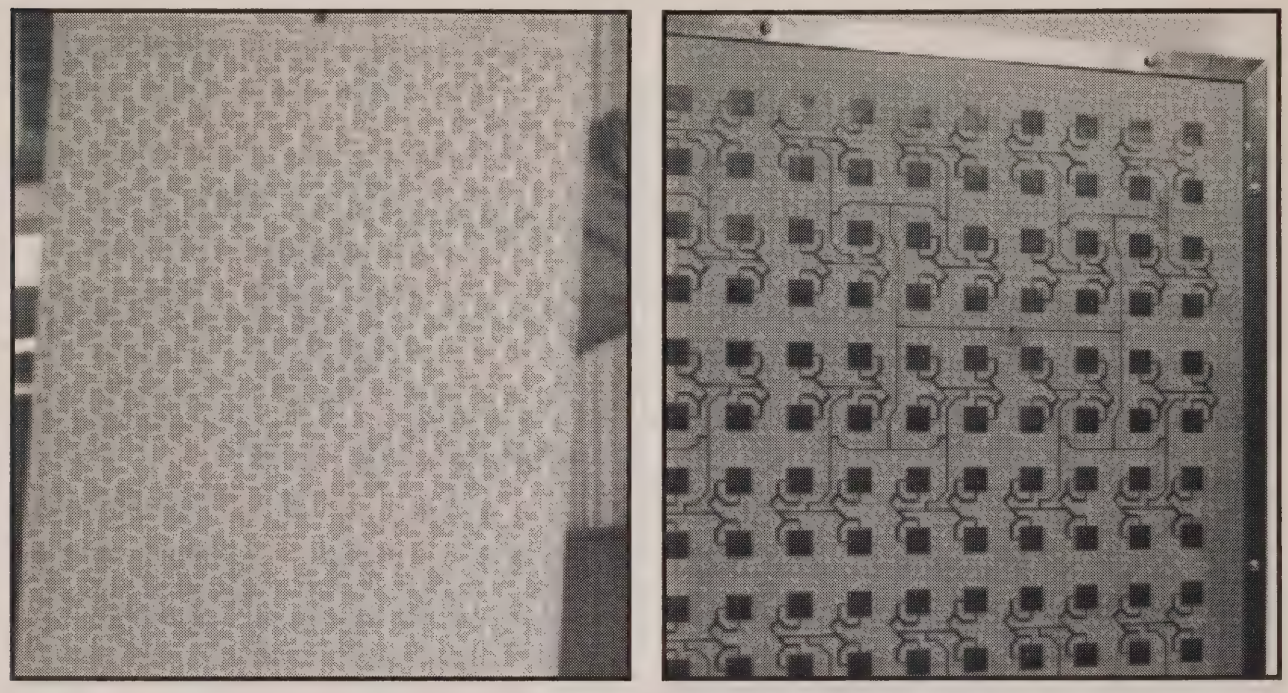
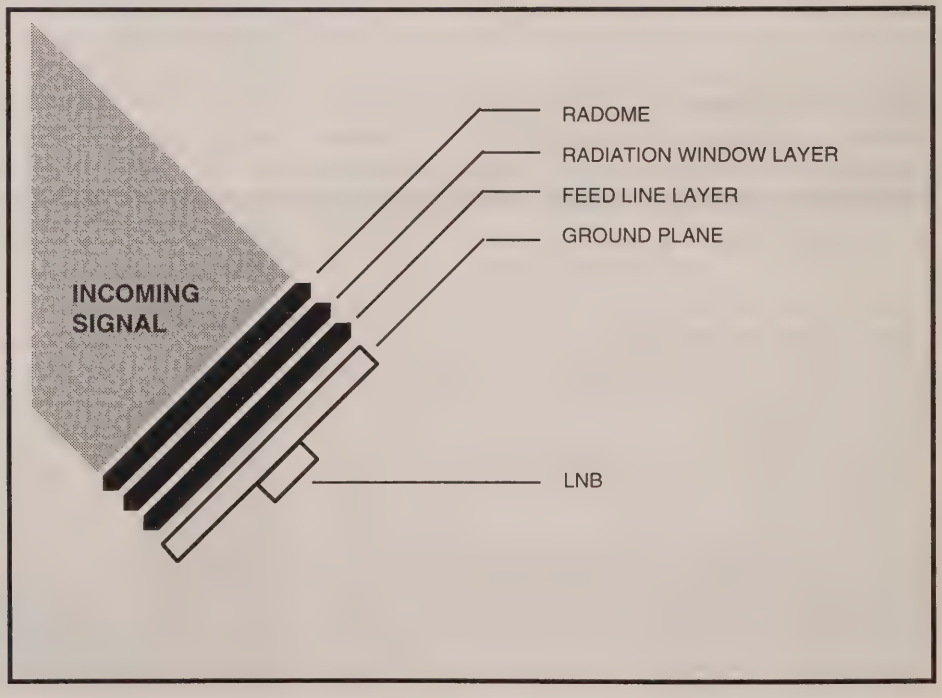


Fig. 7-11a and 8-11b. Early crank and patch flat plate antenna designs developed in Japan. (Photos by Mark Long.)

signals to pass. The second layer is composed of numerous, tiny slot-like copper windows, while the third layer holds the signal combining feed lines. A metal plate at the back of the antenna serves as both an electrical ground and as the antenna's support structure.

Fig. 7-12. Planar array antenna design using polyester films.

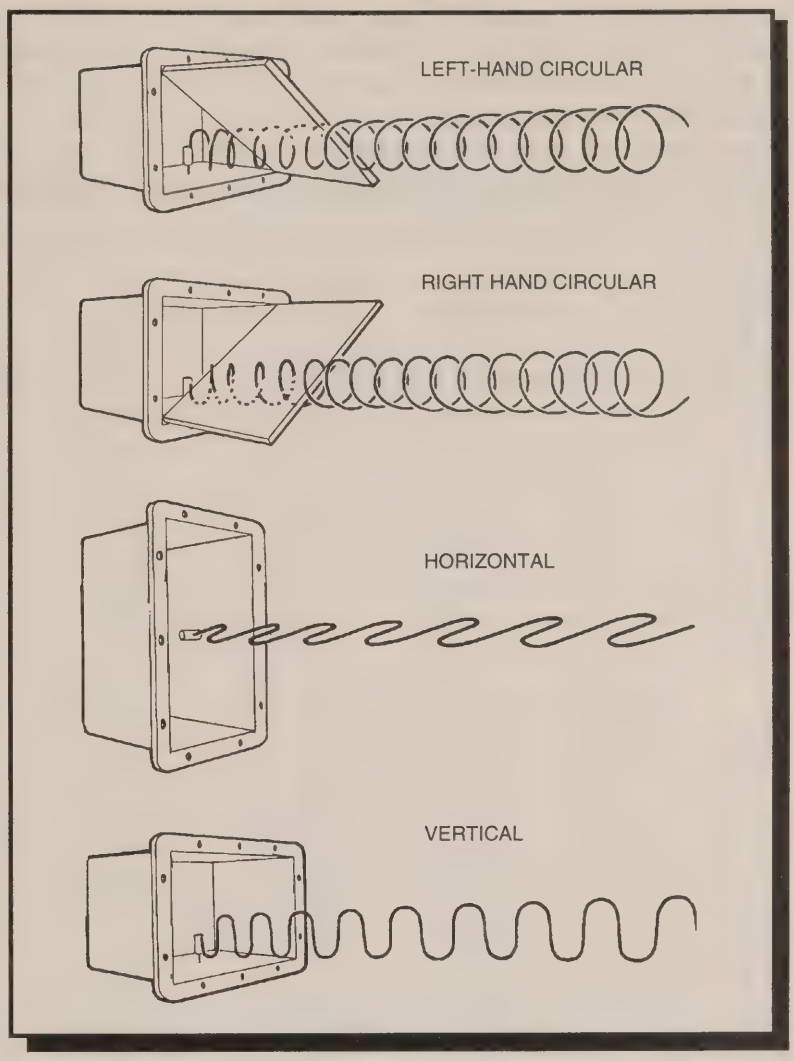


Linear and Circular Polarization Methods

Although most regional and domestic satellites use *linear polarization* to transmit signals in vertical and horizontal planes, many international satellites (and all high power DBS satellites) transmit signals using a helical radiation pattern called circular polarization. A few minor equipment modifications are necessary before satellite earth stations designed to receive linear polarization can receive circularly polarized satellites at maximum efficiency.

With right-hand circular polarization, the electromagnetic field of the signal rotates in a clockwise direction as viewed by an observer looking in the direction of wave propagation; alternatively, it rotates counterclockwise for left-hand circular polarization. Many commercial and private earth stations use a feed not specifically designed to receive circularly polarized signals. An unmodified scalar feed can still receive the signals, but this reduces the satellite signal level by 3 dB (50 percent). Commercial feeds are available that can pick up both circularly or linearly polarized signals without a major reduction in system performance.

Fig.7-13. Circular versus linear polarization formats.



Low Noise Block Downconverters (LNBs)

The first stage of electronic amplification is called the Low Noise Block Downconverter or LNB. Today's LNBs use high electron mobility transistors (HEMTs) with metalized gates that are a mere fraction of a micron wide. Any noise introduced in the early stages of amplification will manifest itself in all later stages of amplification and processing. Therefore, it is vital to keep the noise contributed by the LNB to the lowest possible level when receiving satellites with low EIRP levels.

Ten years ago, a C-band LNB with a 75 degree noise temperature rating cost more than US$ 1,000. Today, increased production and advanced manufacturing techniques make it possible to obtain a 30 degree unit for less than US$ 200.00. Using a 30 degree LNB instead of a 75 degree model can increase the level of the signal arriving at the earth station's receiver by more than a +1.5 dB.

All LNBs have performance curves. Manufacturers of LNBs typically rate their units at the highest noise rating attained at any one frequency within the bandwidth of the product. In some cases, LNBs can contribute substantially less noise at certain frequencies. Before low noise temperature C-band LNBs became avail-

able at low cost and in large quantities, earth station operators used to handpick LNAs (low noise amplifiers, as C-band LNBs were unavailable at that time) with low noise temperature ratings for the specific portion of the satellite frequency band that was of particular interest.

Ku-band LNB Noise Figures

C-band LNBs are rated by their *noise temperatures*, but Ku-band LNBs are graded by their *noise figures*. The following conversion chart lets you transform noise figure ratings back to equivalent noise temperatures. Noise

Fig.7-14. Noise-Figure-to-Noise-Temperature Conversion Chart.

Noise Figure (in dB)	Noise Temp. (in K)	Noise Figure (in dB)	Noise Temp. (in K)	Noise Figure (in dB)	Noise Temp. (in K)
.148	10	2.056	175	3.378	340
.220	15	2.103	180	3.412	345
.291	20	2.149	185	3.446	350
.360	25	2.194	190	3.480	355
.429	30	2.239	195	3.513	360
.496	35	2.284	200	3.547	365
.563	40	2.328	205	3.580	370
.628	45	2.372	210	3.613	375
.693	50	2.415	215	3.645	380
.757	55	2.458	220	3.678	385
.819	60	2.501	225	3.710	390
.881	65	2.543	230	3.742	395
.942	70	2.584	235	3.773	400
1.002	75	2.626	240	3.805	405
1.061	80	2.666	245	3.836	410
1.120	85	2.707	250	3.867	415
1.177	90	2.747	255	3.897	420
1.234	95	2.787	260	3.928	425
1.291	100	2.826	265	3.958	430
1.346	105	2.865	270	3.988	435
1.401	110	2.904	275	4.018	440
1.455	115	2.942	280	4.048	445
1.508	120	2.980	285	4.077	450
1.561	125	3.018	290	4.107	455
1.613	130	3.055	295	4.136	460
1.665	135	3.092	300	4.165	465
1.716	140	3.129	305	4.193	470
1.766	145	3.165	310	4.222	475
1.816	150	3.201	315	4.250	480
1.865	155	3.237	320	4.278	485
1.913	160	3.273	325	4.306	490
1.962	165	3.308	330	4.334	495
2.009	170	3.343	335	4.362	500

levels are significantly higher for Ku-band receiving equipment. Ku-band LNB noise temperatures range from a low of 75 degrees to a high of 180 degrees Kelvin (approximately 1.0 to 2.1 dB in noise figures).

Ku-band satellites use various segments of the Ku-band frequency spectrum depending on their role (FSS or BSS) and service area (ITU Regions 1, 2, and 3). In the United States, Fixed Satellite Service (FSS) satellites operate in the 11.7 to 12.2 GHz frequency spectrum, while Broadcast Satellite Service (BSS) spacecraft operate within the 12.2 to 12.7 GHz frequency range. In Europe, FSS satellites may operate within one or more frequency segments: 10.7 to 10.95 GHz, 10.95 to 11.2 GHz, 11.2 to 11.45 GHz, 11.45 to 11.7 GHz, or 12.5 to 12.75 GHz, while the BSS satellites operate within the 11.7 to 12.5 GHz frequency range. In Asia, the 10.95 to 11.7 GHz and 12.25 to 12.75 GHz most often are used by FSS satellites, while the 11.7 to 12.25 GHz frequencies are reserved for BSS satellite operations. An LNB that can receive the correct Ku-band frequency range must be used by the desired satellite before the receiver can tune in to the available programming.

This problem is further compounded when the earth station operator wishes to receive satellites operating within different frequency segments with the same satellite antenna. Fortunately, universal, band-switching LNBs are now available which allow reception of both the 10.65 to 11.7 GHz and 11.7 to 12.75 GHz Ku-band frequency segments. A switching voltage (13/17 volts d.c.) sent up the coaxial cable by the receiver commands the universal LNB to switch frequency segments whenever required.

International Satellite TV Receivers

Satellite earth station receivers manufactured for domestic satellite reception in North America are not totally compatible with some of the technical standards used by international satellites. Some receivers require accessories for adequate reception; a few manufacturers provide special versions of their receivers for viewing international satellite signals.

Many European, Asian, African, and South American countries do not use the NTSC video standard used in the United States and Canada. Most of these countries use a video standard based on the higher-resolution 625-line picture instead of the 525-line format. (Refer to the appendices for a country-by-country list.)

After a video signal passes through the demodulator of a satellite receiver, the signal is shaped by de-emphasis and low-pass filters. These filter networks restore baseband frequency response flattened by demodulation. It is necessary to modify these receivers for proper reception of any International Radio Consultive Committee (CCIR) video transmission format. Some manufacturers will modify their receivers for 625-line video upon request. A few receivers include a switching network that allows the user to view either 525- or 625-line video and also substantially improves signals at or below receiver threshold. The switching network eliminates picture streaking and color smearing caused by the incorrect component values.

Transponder Selection Circuitry

There are major differences in the transponder frequency schemes used by domestic, regional, and international satellites. The center frequency of the video signal is offset from the preset center frequencies used by many channelized receivers and integrated receiver/decoders (IRDs).

There are programmable satellite receivers that will accommodate any of the various satellite frequency schemes. Sometimes, commercial earth station operators may dedicate a receiver to the reception of a particular satellite transponder format by pre-setting the internal receiver adjustments to the center frequency of each available transponder. Wideband receivers with an IF input frequency range of 950 to 1750 MHz also are needed to receive the low C-band transponders aboard the INTELSAT VI, Raduga, Gorizont, AsiaSat 2, Apstar, Palapa C and other new C-band satellites which use frequencies that are below 3.7 GHz.

International Satellite Audio Reception

International satellite operators use subcarrier frequencies that range throughout the entire 5.0 to 8.5 MHz audio subcarrier spectrum.

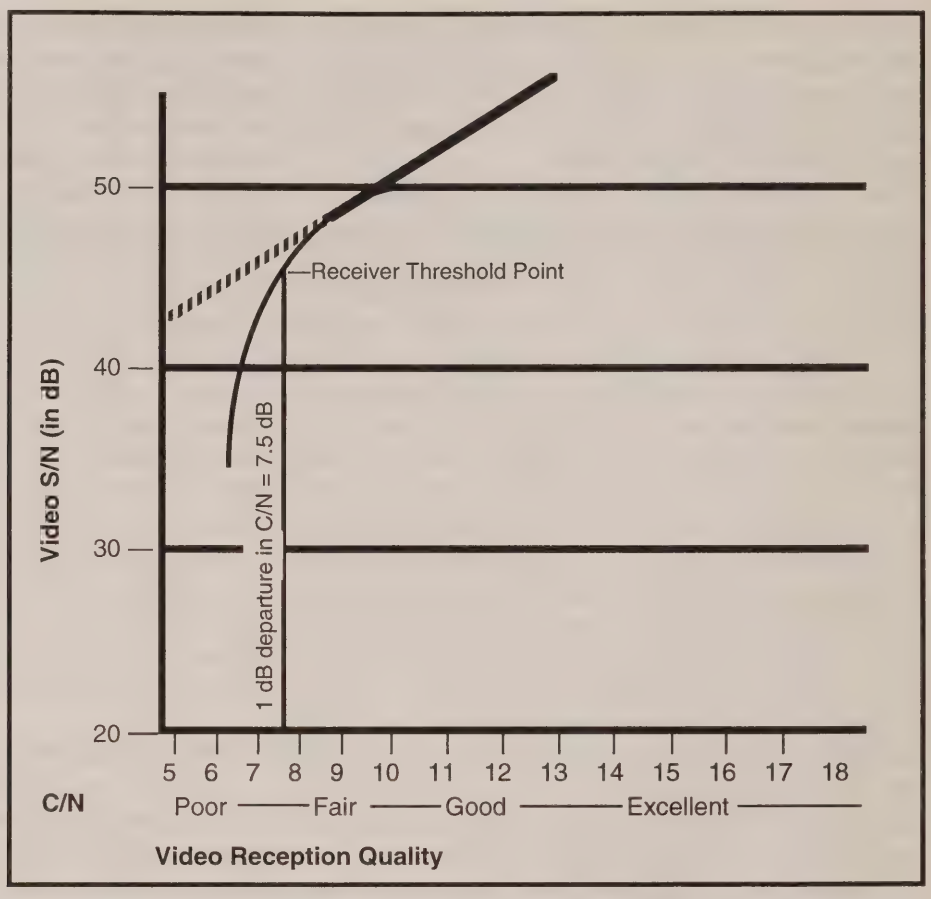


Fig.7-15. As signal level drops below receiver threshold, video rapidly worsens.

INTELSAT and Intersputnik, among others, usually transmit sound on frequencies other than the typical 6.2 or 6.8 MHz audio subcarrier assignments of North American domestic satellites. Receivers with continuous tuning or programmable audio subcarrier control can access the entire 5.0 to 8.5 MHz range of available audio subcarrier frequencies. These are recommended for situations involving multiple subcarrier frequencies.

Earth station operators also may encounter several audio subcarrier transmission formats, such as Wegener Panda stereo, which have unique deviation and bandwidth performance characteristics. A receiver should be selected that conforms to the performance characteristics of the desired service or services.

Receiver Threshold

The threshold level of any satellite TV receiver is the point at which the relation between the carrier-to-noise (C/N) of the incoming signal and the signal-to-noise (S/N) level of the resulting video becomes nonlinear (see Fig. 7-15).

C/N can be calculated by adding the signal strength level to the total system noise level (the combination of external and internal noise generated within the amplifier itself) and dividing the sum by the noise level alone. When noise in a satellite TV system maintains a constant level, the stronger the satellite signal and the larger the dish, the higher the C/N produced. Any impulse noise, or *sparklies,* which appear in the video gradually disappear as the C/N level generated by the incoming signal approaches the threshold level of the receiver. At a margin of 1 or 2 dB above threshold makes any stray sparklies will disappear.

When operating above threshold, each 1 dB increase in C/N causes a corresponding 1 dB increase in the S/N of the video. However, when operating below threshold, a 1 dB decrease in C/N can decrease video S/N by several dBs.

The threshold level of most satellite receivers is 7~8 dB C/N. A +2 dB margin will make sure there are no sparklies in the video and will offset any signal loss that may occur as the satellite's TWTAs weaken with age. Sometimes, however, achieving a +2 dB margin may not be practical.

Some noise may be tolerable to noncommercial users. At a margin of 0 dB—threshold—the video only has a few sparklies. At -1 to -2 dB, the incidence of impulse noise increases, but the video is still viewable. As the signal drops -3 dB or more below threshold, the video is increasingly washed out by impulse noise and not enjoyable to watch. A few of the satellite receivers on the market today have built-in threshold extension or video noise reduction circuitry that can extend the receiver threshold to less than 7 dB C/N.

The satellite footprint maps provided by the satellite operator and/or service provider will supply you with the required EIRP levels at the site location for each of the available satellites. These EIRP signal levels, however, are averages that may vary by one or more dB. Allow for an additional margin level to ensure that current reception goal are achieved and that system performance does not deteriorate as the satellites approach the end of their operational lifetimes.

Narrowing the Bandwidth

Frequency modulated (FM) video transmissions theoretically generate an infinite number of FM sidebands that appear at spaced intervals from the transponder center frequency. However, most of the power is concentrated within lower-harmonic sidebands that fall inside a 36 MHz bandwidth for full-transponder signals, or inside an 20 MHz bandwidth for half-transponder transmissions.

An adjustable bandpass filter can be used to improve reception of half-transponder signals transmitted by INTELSAT and satellite operators. For example, some satellites have 54-MHz-wide transponders that simultaneously

Fig. 7-16. Through the use of a variable bandpass filter, reception of marginal satellite TV signals can be appreciably improved by reducing the bandwidth of the incoming signal. (Photos by Mark Long.)

can transmit two TV signals. The satellite operators accomplish this by dividing the transponder into two half-transponder channels, each with an effective bandwidth of about 23 MHz.

Many satellite TV receivers are available with built-in adjustable bandpass filters that can be programmed on a transponder-by-transponder basis to optimize receiver performance for each of the available satellite TV services..

These adjustable bandpass filters eliminate internally and externally generated noise located above and below the spectrum of frequencies inhabited by each video signal. This can result in a dramatic improvement in the receiving system's C/N.

The level of noise admitted into the receiver's demodulator is directly proportional to the bandwidth of the receiver's intermediate frequency (IF). Raising the system CN/R even closer to receiver threshold means further reducing the bandwidth. When the IF bandwidth of the receiver is reduced, the strongest slice of incoming signal is picked up while eliminating the lower-level FM sidebands and system noise that inhabit the outside edges of the transmitted RF spectrum.

Adjustable bandpass filters connect to the IF loopthrough connections on the back of most satellite TV receivers and IRDs. A short jumper cable on the back panel of most receivers and IRDs bridges the input and output ports of the receiver's second IF circuitry. Disconnect this jumper and add two cables which connect the receiver's IF input and output jacks to the input and output ports of the filter.

The effect of narrowing the bandwidth is computed with the following formula:

C/NR increase (in dB) = 10 log (B2/B1)

where B2 and B1 are the before and after bandwidths.

When a constant value is assigned to the sum of the antenna and LNB noise temperatures, a 3 dB increase in system C/N results when the bandwidth of the receiver is cut in half. This is exactly what happens if we reduce the receiver bandwidth from 36 MHz to 18 MHz. A further 3 dB of C/N results when the bandwidth is reduced from 18 MHz to around 9 MHz, for a total overall improvement in system C/N of 6 dB. Normally, a 16 foot (5m) dish with a 60 degree LNB would provide only the faintest ghost of a picture when receiving an INTELSAT 21 to 22 dBW global beam signal. Reducing the bandwidth allows us to receive pictures that otherwise would be unobtainable.

Threshold Extension Penalties

Reductions beyond the actual transmitted bandwidth of the satellite signal can deliver additional C/N gains, but only at the expense of video quality. To obtain a totally faithful reproduction of the video color and detail information, the receiver must pass the entire transmitted bandwidth of the signal. However, many private users may be satisfied with less than broadcast-quality reception. Sometimes the increased clarity gained by eliminating impulse noise more than compensates for the loss of some color fidelity and picture detail.

A bandwidth as narrow as 12 MHz may be acceptable when receiving half-transponder video. Further bandwidth reductions to 10 MHz or less places audio subcarriers beyond the -3 dB passband of the filter. If a separate circuit to retrieve the audio portion of the programming, picture detail also is lost, which results in a "softening" of the video, and phase delays cause the video to streak or smear.

If the bandwidth is narrowed even further to less than 7 MHz, the NTSC 3.58 MHz color subcarriers, or the SECAM or PAL color subcarriers in the 4 MHz region, can fall outside of the filter's -3 dB passband points. Color reception is then severely distorted or eliminated altogether. Also, the tips of the video sync pulses are attenuated and noise truncation of the video causes impulse noise to reappear in the monochrome video picture.

Chapter 8

Satellite Installations For Television Receive Only (TVRO) Applications

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The following chapter provides a basic overview of the various stages required in the installation of satellite television receive only (TVRO) systems. Although the antenna and other major electronic components will come with their own assembly and operating instructions, anyone who is relatively unfamiliar with the required installation procedures will benefit from this overview of how the individual parts within the system function together, as well as how other criteria—such as site selection and initial antenna alignment—can affect the performance of the completed system.

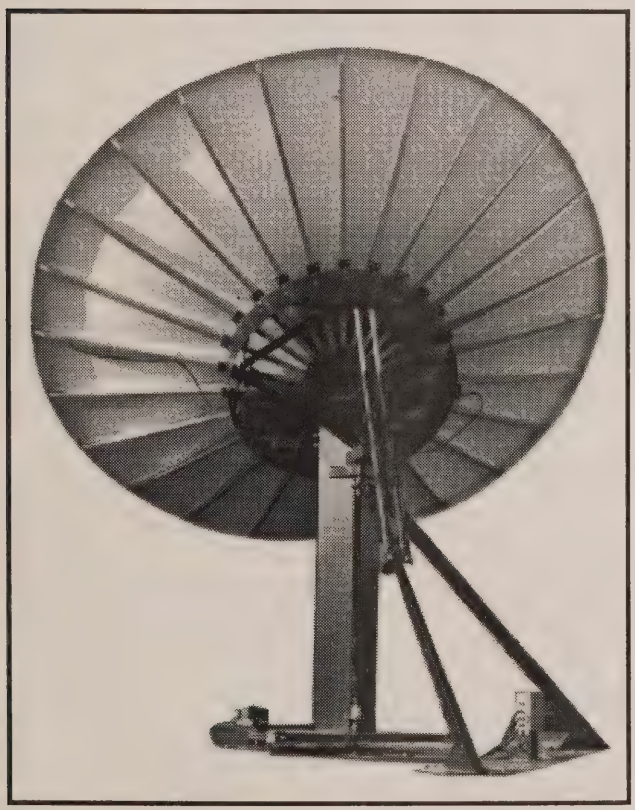


Fig. 8-1. Large aperture antennas require the use of a heavy duty mount support structure. (Photo courtesy Astroguide.)

Site Surveys

Satellite signals are microwaves that travel in a straight path along the line of sight. Geostationary satellites are positioned over the Earth's equator. To receive their signals from locations in the Northern hemisphere, the satellite receiving antenna must have an unobstructed view of the Southern (or Northern for sites located below the equator) sky. An inspection, or site survey, of the proposed earth station location should be made at the outset to ensure that there are no tall buildings, trees, power poles, or other substantial obstacles to prevent the signals from reaching the receiving antenna.

If the site survey takes place in the late Fall or Winter, the foliage of nearby trees and bushes that will be in place during the Spring and Summer months should be taken into account. Future construction plans of nearby buildings also must be considered; any new structures could be in a position to affect your reception.

A preliminary site survey can be conducted by standing at the proposed antenna site and looking toward the South (or North for sites located below the equator). For total access to all available geostationary satellites viewable from the site location,a clear and unobstructed view of the sky all the way from the Southeast to the Southwest (or Northeast to Northwest or sites below the equator) would be required. However, the view from many sites—especially those in metropolitan or suburban areas—will have obstructions in one or more directions. At these restricted sites, some satellites may not

be in view. To determine precisely which satellites will be visible from the site location, knowledge of a few basic techniques for locating the satellites is required.

Azimuth and Inclination

Azimuth and inclination (also called elevation) are the two basic coordinates used to determine each satellite's position in the sky. The azimuth coordinate represents the bearing of the satellite from your location, while the inclination is the angle of tilt at which the antenna looks up at the sky.

Every satellite within view of a specific installation has its own unique pair of azimuth and inclination coordinates. Given the site's latitude and longitude, the coordinates for any satellite are fairly simple to calculate. The inclination/azimuth table which appears in the appendix can be used to estimate the azimuth and inclination coordinates for all available satellites.

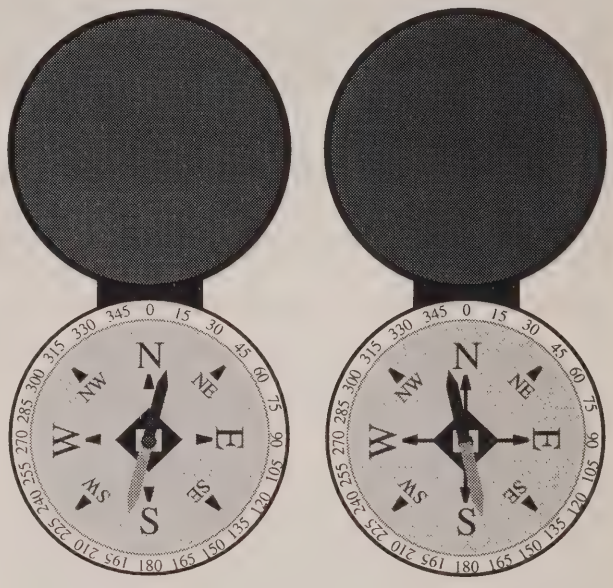


Fig. 8-2. If true north is east (or west) of magnetic north, rotate compass in your hand until the needle points at the difference in degrees east (or west).

Once the azimuth coordinate for a specific satellite is known, a compass can be used to determine the precise direction from the site location. The initial compass reading, however, must be adjusted, or corrected, to account for variations between magnetic North and "true" North (or true South for locations below the equator). Although there are maps available which can provide the required correction factor, the location of the Earth's magnetic North Pole actually shifts periodically. Unless the magnetic deviation map is fairly current, it is advisable to contact the control tower at the nearest airport to estimate the correction factor for the site location.

If true North is East of magnetic North, the correction factor must be subtracted from the compass readings; when true North is West of

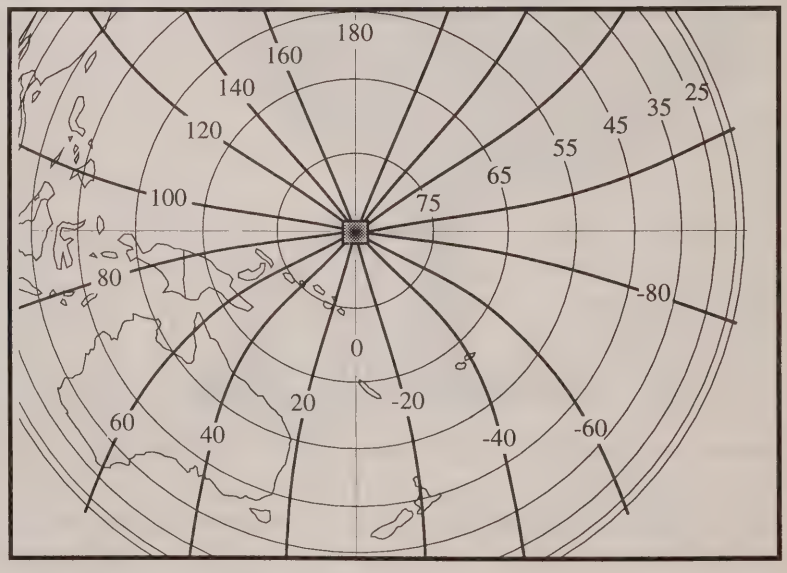
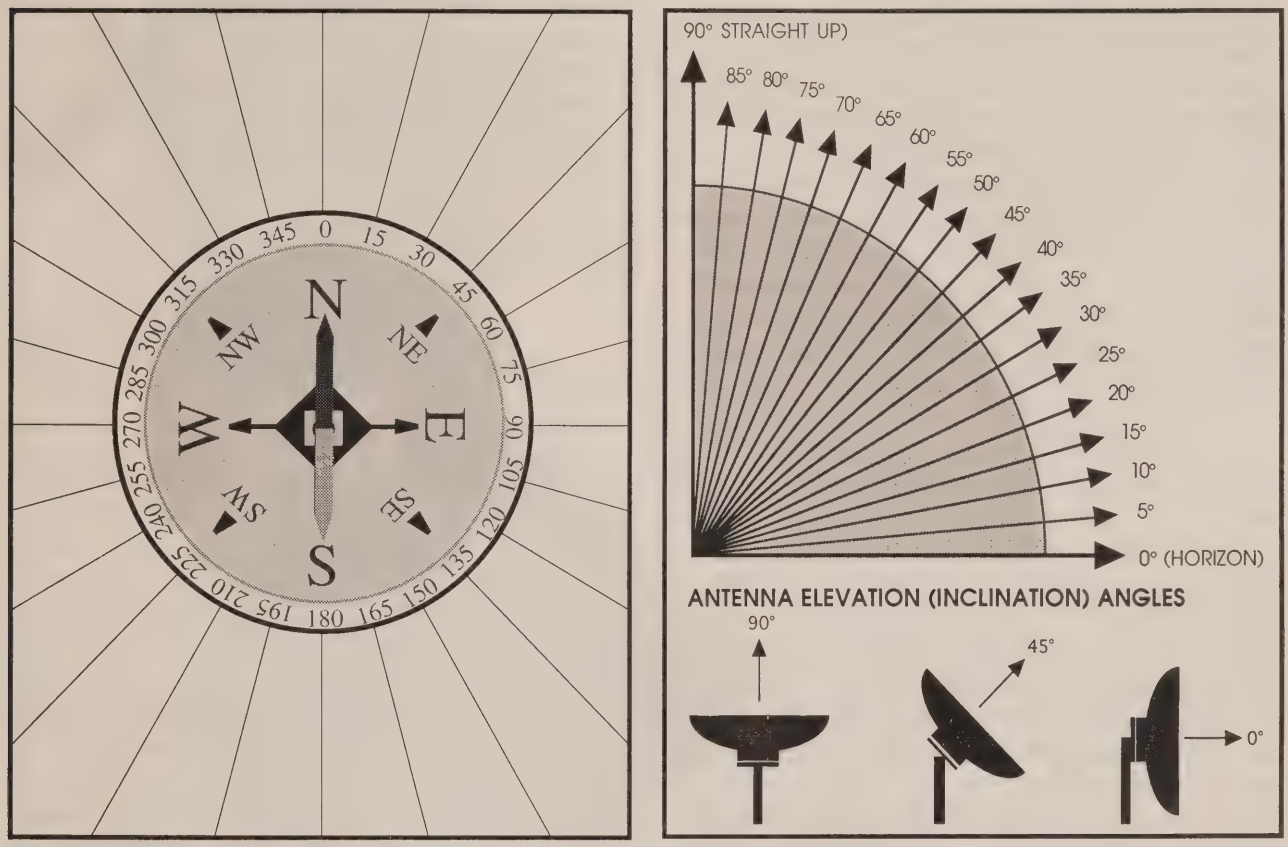


Fig. 8-3. Azimuth and inclination coordinates for the Optus orbital assignment of 164° east longitude. While many satellite operators provide similar graphics, these maps merely provide 'ballpark figures' rather than the exact azimuth and inclination coordinates delivered by the readily available computer programs.

Fig.8-4a & 8-4b. Azimuth (left-top view) and Inclination (right-side view). See the Azimuth/Inclination Chart in the appendix to compute the correct pair of angles for each satellite available from your site location.



magnetic North, the correction factor is added. All compass readings should be taken out in the open, well away from large metal objects or overhead a.c. power lines and transformers which could affect the accuracy of the measurements made.

From any location, the satellite located nearest to a line running from true North to true South (opposite for stations in the Southern hemisphere) will be at the highest point of elevation of all the available geostationary satellites. The further away the satellite's azimuth coordinate is from due South (or due North), the lower its inclination in the sky. At some point, the inclination of satellites to the extreme West or East of the site location will fall below the horizon, preventing reception. That is why satellite earth stations in Europe cannot view North American domestic satellites, and vice versa.

An inclinometer is used to measure the degrees of inclination, or "tilt", of the dish. Inclinometers, which sometimes are referred to as "angle finders", are readily available from sources within the satellite TV industry. Hardware shops and department stores may also sell inclinometers to carpenters who use them to measure roof pitch angles.

An inclinometer also can be used during the site survey to determine whether obstructions would block out any of the available geostationary satellites. Position the inclinometer on a level surface at the center of the site, and align it with the bearing, or "azimuth", of the satellite under consideration. Then tilt the inclinometer back until it indicates the inclination of the desired satellite. By sighting along the edge of the inclinometer, you should be able to tell if any obstacles are between the site and the satellite's location in the sky.

If there are obstructions such as trees or other foliage that would interfere with reception of one or more satellites, it may be possible to remove them. Where the obstruction is part of a nearby building or hill, it may be posssible to move the proposed site from ground level to a more advantageous rooftop location. A tall pole extending from the ground up the side, and anchored to, a building may allow the antenna to peer over the roof and receive a clear view of the satellites. Small antennas can be fastened to the side, eave, or roof of a building with the appropriate hardware. For extreme cases of obstruction, however, you may have to consult a real estate broker.

Terrestrial interference (TI) from telephone transmitting stations also can restrict or even preclude C-band satellite reception in some areas of the world. If the site location is between two of these microwave links, reception may be severely affected. In some areas, especially around airports, shipyards, or military installations, there are other terrestrial microwave services which can cause interference.

One way to check for possible microwave interference—as well as to ensure that there are no physical obstructions—is to use a portable antenna to receive signals from the desired satellites. To detect all potential interference, the test should be performed right at the spot where the proposed earth station will stand. A difference of only a few feet can be critical in some instances.

This survey should be made on a weekday, when telephone and other microwave traffic is at its peak. If the site location is in a business area, test during business hours; in a residential area, check later in the day. In the event that some interference is present at the site location, filters and other accessories are available that often will eliminate the problem.

In some communities, especially in the U.K. and other European countries, there are zoning and town planning ordinances which place severe limitations on just where and how satellite earth stations can be installed. For example, antennas may not be permitted on the front of the building or where it can be viewed from ground level. Make sure that the installation under contemplation will comply with all local ordinances and/or covenants.

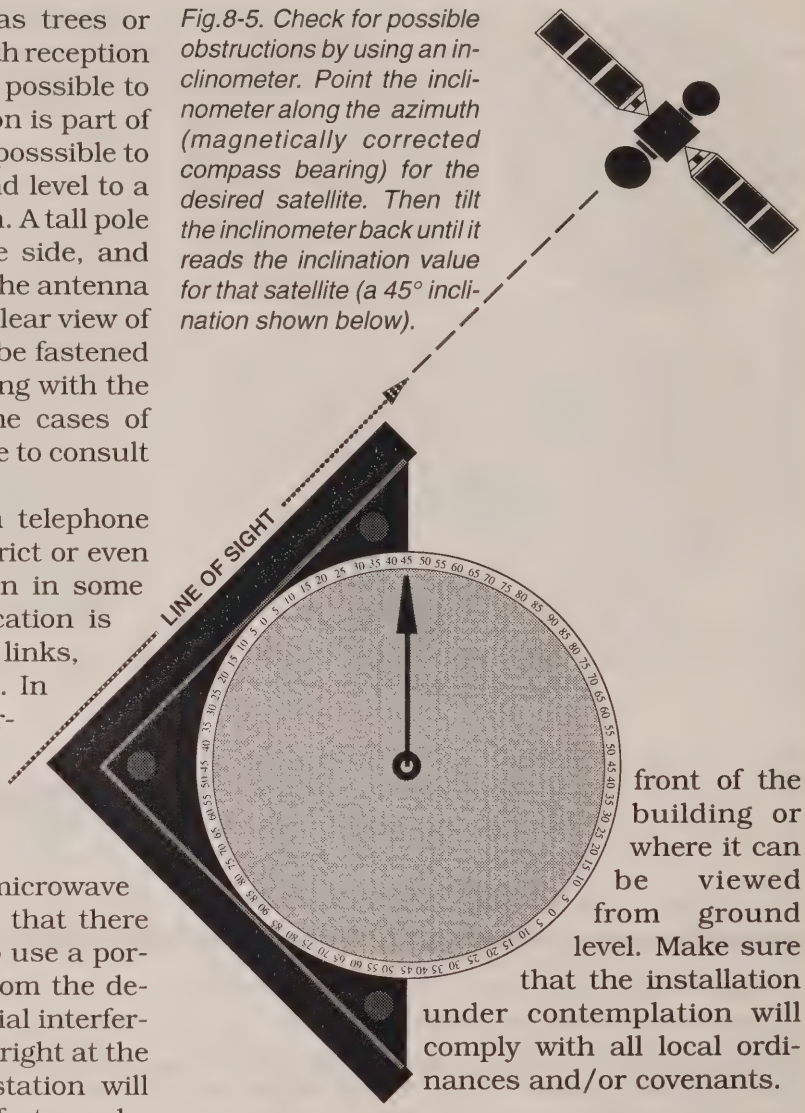


Fig.8-5. Check for possible obstructions by using an inclinometer. Point the inclinometer along the azimuth (magnetically corrected compass bearing) for the desired satellite. Then tilt the inclinometer back until it reads the inclination value for that satellite (a 45° inclination shown below).

Small Aperture DTH Installations

With the proper tools and a modicum of enthusiasm and effort, it should not be difficult for any individual to install a fixed satellite antenna for receiving an individual direct-to-home (DTH) satellite or multiple DTH satellites (such as Astra, Thaicom, or DirecTv) which are collocated at a single orbital position. In many cases, the most important step will be to select and install the appropriate antenna mount for the specific location and type of building.

Selecting the Mount. Mounts are manufactured to accommodate a variety of possible placements such as on the ground, attached to an outside wall, or under the eve of a house.

Fig. 8-6. An inexpensive signal meter. (Courtesy Apex.)

Roof mounts are available that either penetrate the surface of the roof and attach to the building's rafters or directly upon the top of a flat roof. Above all, select the type of mount which can be installed where the antenna will have a clear and unobstructed view of the satellite or satellites of choice throughout the year.

Attaching the Antenna to the Mount. Once the antenna's mount has been securely fastened to the building or a supporting pole, mount the antenna as indicated in the directions. Do not fully tighten down those bolts, which anchor the antenna at a specific position of inclination and azimuth, until the antenna has been adjusted for maximum signal reception. Mount the feedhorn and LNB onto the feed support supplied with the antenna.

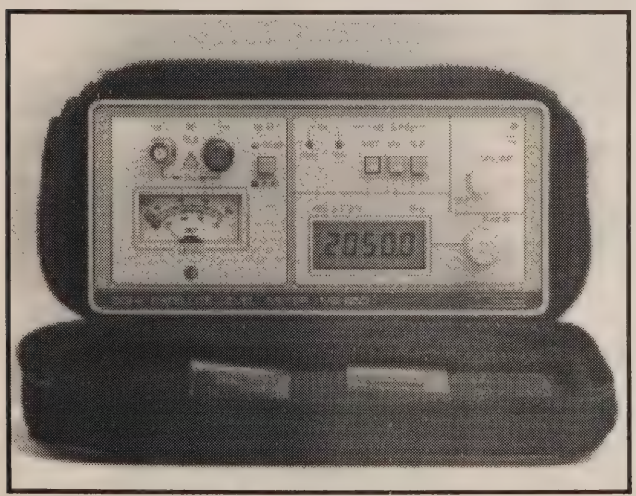


Fig. 8-7. A technician's satellite level meter incorporating advanced functions such as a digital IF frequency readout and LNB voltage supply. (Courtesy Promax.)

Running the Cables. A coaxial cable will have to be installed between the receiver's location within the building and the feedhorn and LNB at the antenna. Systems dedicated to the reception of satellites using two senses of polarization to transmit TV signals also will require a two- or three-wire cable to connect the feedhorn's polarization circuitry to the receiver. Cable clips can be used to fasten these cables to the side of the building. The cable should be installed a bit below and then back up to the hole into the building, thus providing a "drip loop" to prevent rain from running down the cable and into the building. Type "F" connectors are crimped onto each end of the coaxial cable.

The power for the LNB also is supplied by this coaxial line. Whenever the satellite receiver is plugged into the building's a.c. wall receptacle, electricity is being sent up this line. To avoid a short circuit that would blow the receiver's fuse or circuit breake—or even damage the LNB—always unplug the receiver before connecting or disconnecting the system's coaxial cable.

Peaking Antenna Performance. Before connecting the cable to the LNB, determine which method will be used to accurately aim the antenna at the satellite location of choice. One method is to view the available TV services from this satellite while adjusting the antenna's alignment. Then fine tune the antenna pointing until all stray impulse noise or "sparklies" have been eliminated for all available channels. Something relatively close to maximum system performance can be obtained using this method. To totally peak system performance, however, some kind of signal meter should be used to ensure that the highest signal levels possible are obtained.

It is very important to peak system performance at the outset, so that the amount of signal reaching the receiver exceeds the unit's threshold level. This signal margin above receiver threshold will compensate for any degradation of signal which occurs during adverse weather conditions.

The front of the receiver may have a signal

level meter, an LED signal level display, or an on-screen graphic which displays relative signal strength. Any of these signal strength indicators can be used to peak reception if the receiver (or TV in the case of an on-screen graphic signal indicator) can be moved into a position which can be viewed from the antenna. The receiver and TV set often are brought outside for this purpose—especially when peaking an antenna that is mounted on the ground or a flat roof. In this case, an extra length of coax and LNB/feedhorn cable will be needed to temporarily connect the receiver to the feed and LNB.

It is impractical, however, to carry the receiver and/or TV up a ladder to peak an antenna mounted on the side of a building or under the eave. An in-line, signal-strength meter is a better choice for performing this task. What's more, a dedicated signal-strength meter also will be more accurate and sensitive than the meter built into the satellite TV receiver. Best of all, some portable meters provide an audio tone which increases in pitch as the signal becomes stronger. As the antenna is adjusted slightly to the right/left and up/down, the audio tone provides an immediate indication of changes in signal intensity.

When using a signal strength meter be sure that the correct satellite is being viewed before beginning the peaking process. Scan through the available channels at the outset—and again at the end— of the installation process to ensure that acquisition of the correct satellite has occurred.

Some signal strength meters will supply the voltage needed to power the LNB and therefore can be connected directly to the LNB's output connector. Signal meters which do not supply power to the LNB will have to be inserted in the coaxial line running from the receiver to the LNB using a device called three-way "tap". This

Fig. 8-8, 8-9, & 8-10. Lifting a 5-meter reflector onto the mount in Bolivia. (Photos by Mark Long.)

Fig. 8-11. Mesh antennas like this 4.5 meter Paraclipse are designed to be assembled right on the antenna mount. (Photo by Mark Long.)

tap supplies three connectors: one connects to the LNB, the second to the receiver, and the third supplies the connection to the meter so that the required signal strength measurements can be made. Once the antenna alignment as been completed, tighten down all of the mounting bolts to prevent strong winds or rain from repointing the antenna.

Setting the Polarization. The feedhorn support which comes with the antenna holds the feedhorn and LNB at a fixed position towards the front of the antenna. If this support has an adjustment for setting the distance between the feedhorn and the surface of the dish, try moving the feed in and out at tiny intervals of a fraction of an inch to see if the signal strength improves.

High power DBS satellites such as Sirius, TV Sat, TDF, Thor, Tele-X, and Hispasat each use a single sense of circular polarization (either right-hand or left-hand) to transmit all the available channels. In this case, there is no need to fine tune the polarization of the feedhorn for DTH receiving systems because the feed's polarization setting was pre-set at the factory for maximum signal reception. Many other satellites, however, use opposite senses of linear (horizontal/vertical) polarization to transmit a greater number of channels from a single orbital position. In this case, the feedhorn's polarizer must be "skewed" by adjusting the receiver's polarization or skew control and programming the settings into receiver memory. You should be able to skew slightly past the setting for maximum signal level when receiving channels using either sense of polarization.

Large Aperture Antenna Installations

Large aperture antennas require different installation methods than their smaller counterparts. In most cases, large aperture antennas will be required to track multiple satellites. In some cases the antenna must be able to accurately track from one horizon to the other. If reflector assembly is conducted at ground level, several people will be needed to lift the reflector onto the antenna mount; alternatively, a crane or other mechanical device can be used to hoist the antenna into place. Other large aperture antennas are designed so that they can be assembled piece by piece directly onto the antenna mount. Both of these construction methods require that the installer check the curvature accuracy of the antenna following assembly in order to ensure that the surface has retained a true parabolic shape.

Rooftop and Wall Mount Installations

For rooftop and wall mount installations—especially for large C-band installations—the roof or wall structure must be able to support the weight of the dish, as well as withstand the uplift forces resulting from moderate and high-speed winds. Because roof top installations are more susceptible to terrestrial microwave in-

terference than those on the ground, a site survey with a spectrum analyzer or an on-site rooftop demonstration with a small portable dish is an absolute necessity for any C-band installation. If there are other satellite installations in the immediate area, check with their operators to see if they are experiencing any interference problems.

Pouring the Foundation

For most large C-band installations, you will need to construct a concrete foundation for the mount. In the case of a pole-mount antenna, a steel pipe is placed in a hole in the ground and embedded in concrete. Because it will take a few hours for the concrete to harden, it is a good idea to set the pole the day before you construct the antenna. Quick drying concrete products also are available which will set up in less than an hour. Be sure to use a level to ensure that the pipe is "plumb" before the concrete sets.

Other types of dish mounts will require a concrete pad for the foundation. Concrete piers extending well below the frost line should be incorporated into the pad design. Certain types of antenna mounts merely need a level surface.

Assembling The Antenna

The antenna will come with a detailed set of instructions covering all the essential construction information. When the antenna arrives at the site location, check to see that all parts listed in the manual are present and accounted for. Read over the instructions to see what tools and other materials will be required. If assistance during assembly is recommended—as in the case of a large dish (2m or more in diameter)—arrange to have one or more people available to help lift the dish onto the mount. On the evening prior to assembly, check the local weather forecast to ensure that rain or heavy winds are not in the forecast. Begin assembly early in the day to allow enough time to complete the project.

If the antenna is large enough to consist of multiple panels or "petals", take care during the assembly to ensure that you get the most accurate curve possible. If the construction and installation of a large aperture will take more than a single day to complete make sure that the antenna is fully assembled and anchored before leaving it unattended.

Fixed Mount Alignment

For DTH satellite TV systems dedicated to receiving a single satellite location in the sky, the alignment process is very simple and straightforward. A mount for an antenna dedicated to receiving Thaicom 1 & 2 collocated at 78.5 degrees east longitude, for example, will be

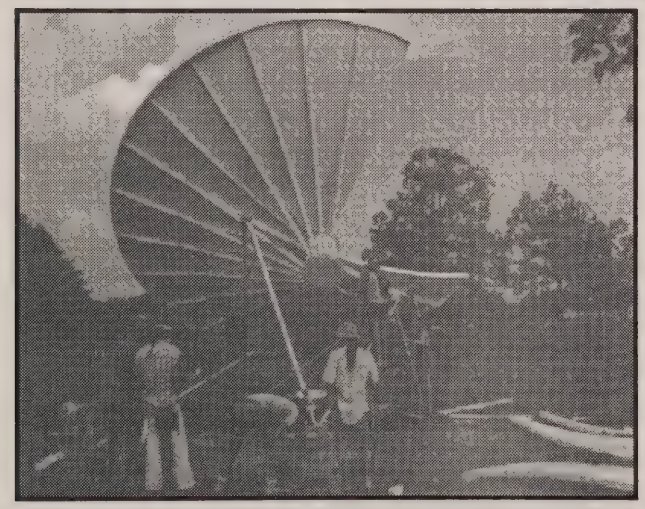


Fig. 8-12. Installation of a 6 meter antenna composed of twenty-four solid aluminum panels. (Photo by Mark Long.)

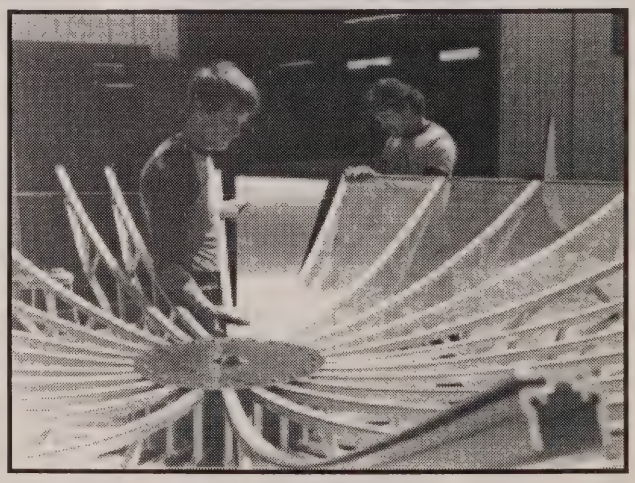


Fig. 8-13. Attention to surface accuracy is extremely important when assembling a mesh antenna. The mesh should be fastened so that there are no noticeable bumps or depressions in the surface material.

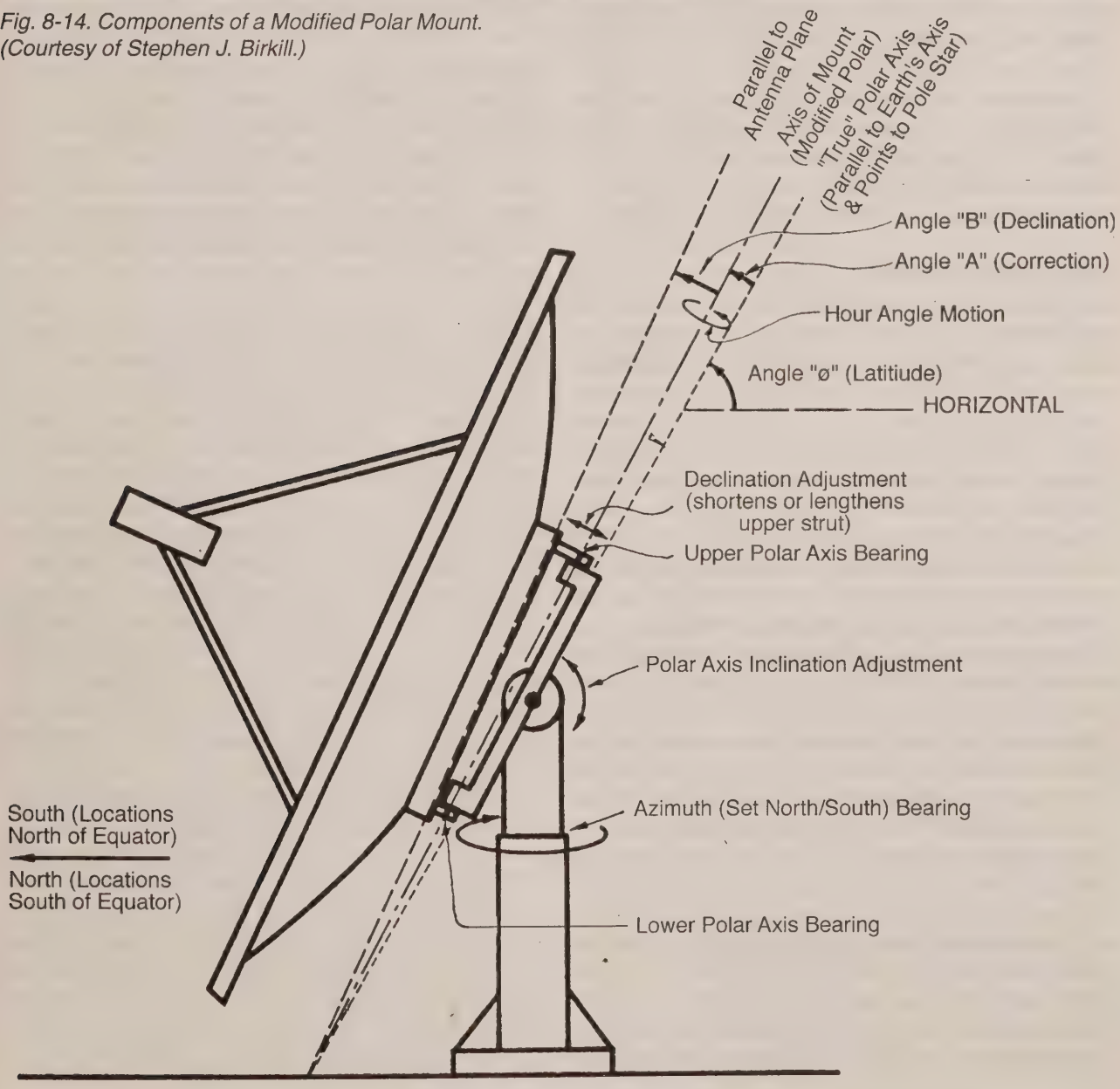
adjusted to the correct azimuth and inclination coordinates, with the azimuth angle corrected from magnetic to "true" North for the specific site location. Fine tuning adjustments to the antenna's alignment will be made while receiving a satellite TV channel.

When mounting the antenna onto its pole or mounting braket, snug the bolts just enough to hold the antenna in place. Tightening the bolts down firmly on the pole should be one of the very last things you do, and should be done only after you have "peaked" the antenna pointing for maximum signal level from a TV channel received from the desired satellite or collocated satellites. Tightening beforehand can dimple the pipe, making it more difficult to make subtle adjustments in alignment.

Modified Polar Mount Alignment

TVRO systems which will be receiving signals from satellites at multiple orbital locations in the sky will require a far more complex align-

Fig. 8-14. Components of a Modified Polar Mount. (Courtesy of Stephen J. Birkill.)


Parallel to Antenna Plane
Axis of Mount (Modified Polar) "True" Polar Axis (Parallel to Earth's Axis & Points to Pole Star)
Angle "B" (Declination)
Angle "A" (Correction)
Hour Angle Motion
Angle "ø" (Latitiude)
HORIZONTAL
Declination Adjustment (shortens or lengthens upper strut)
Upper Polar Axis Bearing
Polar Axis Inclination Adjustment
Azimuth (Set North/South) Bearing
Lower Polar Axis Bearing
South (Locations North of Equator)
North (Locations South of Equator)

ment procedure. These antennas will be equipped with a specially modified "polar" mount.

The pivotal axis of a modified polar mount antenna must be accurately aligned to true North. Even when this alignment is done with an engineer's transit, slight inaccuracies in the measurement may result, causing uneven tracking of the geostationary satellite arc. Corrected compass readings may be even further off the mark. While compass readings may be useful during the site survey for locating a clear view of the satellites, the real test of the mount alignment is the video reception which is obtained.

As with the case of the fixed mount, snug the bolts just enough to hold the antenna in place. Tightening the bolts down firmly should be done only after you have gotten the dish to correctly track all of the available satellites.

Mounting the LNB and Feedhorn

Extreme care should be taken when bolting the LNB to the feedhorn. Do not touch the probe inside the mouth of the LNB. The performance of the LNB can be degraded if grease or dirt adheres to the probe's surface. Also make sure that the neoprene gasket that goes between the feedhorn's flange and the mouth of the LNB is "seated" properly in the groove provided. Otherwise, moisture can seep into this opening and disrupt reception. This is not a consideration if the LNB and feedhorn for the system comes as a single, sealed unit.

The center of the feedhorn must be positioned at the correct distance from the center of the antenna's reflector. The focal distance between the center of the dish and the mouth of the feedhorn will vary between different models of antennas, depending on whether the manufacturer has used a deep or shallow dish design. The exact distance will be provided in the instructions.

There are two feed support styles available for all prime focus parabolic antennas. A "button hook" support, sometimes called an LNB tube, is a single piece of tubing which extends from the center of the dish outward. The button hook support, which is curved so that it resembles a hook, allows the feed to be mounted looking back at the center of the dish.

Guy wire kits are available for larger antennas with button hook supports that will provide the additional stability required for support of both Ku- and C-band LNBs. Ku-band signals are much higher in frequency and therefore have shorter wave lengths. Consequently, the antenna curvature and location of the feed for Ku-band reception must be much more precise than what C-band systems commonly require.

For prime focus antennas, check to ensure that the feed is centered over the dish by measuring from the lip of the antenna to the edge of the feedhorn's opening at four equally spaced intervals around the antenna's rim. This is especially important if guy wires are used to anchor the button hook support. If the feed is centered, these measurements will all be equal. If they are not equal, adjust the tension of the guy wires until the feed is properly centered.

The second type of feed support uses a multi-legged structure to hold the feedhorn and LNB (or LNBs for dual-band systems). These are made up of three ("tri-pod") or four ("quad") straight, equal length pieces of aluminum or steel. Quad supports are inherently more stable than button hook supports, offering enhanced stability for installations requiring multiple LNBs. When mounted at the recommended locations on the antenna's surface, these supports should accurately position the feed at the correct focal length: the distance between the center of the dish and the opening of the feedhorn. The correct focal length for the antenna is provided in the manufacturer's assembly manual.

Once the TVRO system is fully operational, the focal length can be fine tuned by moving the feed in and out in small increments while watching the receiver's signal strength meter or listening to the pitch of a tone indicator. This is easier to do with a button hook than a quad support. This adjustment is particularly important in the fine tuning of Ku-band receiving systems.

The focal length for any antenna can be

computed if the diameter of the dish and its its f/D ratio are known. Focal length = the antenna diameter times the f/D ratio. For example, the focal length of a 10 ft. antenna with an f/D of .45 = 10 x .45 = 4.5 feet (54 inches).

To determine the antenna's diameter, measure across the surface of the dish from one side to the other. The radius equals one half the antenna diameter. The depth of the dish is the distance from the center of the dish to the plane of the rim. Stretch a string across the antenna's rim so that it crosses in the center of the dish. The depth will be the distance from the antenna's center to the string.

Some feedhorns, primarily for larger antennas, will have adjustable scalar rings. These feeds can be broken down into two parts: a round flat "scalar" plate with concentric circles on its surface and the wave guide onto which the LNB is mounted. This wave guide (technically referred to as an "orthomode coupler") fits into the center of the scalar plate and can be adjusted inward and outward.

The distance that the wave guide extends beyond the surface of the scalar plate must be set to correspond to the f/D ratio of the antenna. Consult the manufacturer's assembly directions or use the formula previously provided to determine the correct f/D ratio of the antenna.

The feedhorn's wave guide may be marked to indicate the various f/D ratio settings. Alternatively, the feedhorn may come with an adjustment gauge for setting the correct location of the scalar rings.

Another point to check when performing a prime focus antenna installation: the plane of the feed opening should be the same as the plane of the rim of the antenna. An inclinometer can be used to check that both the feed opening and the antenna's rim are parallel to each other.

Running the Cable

For DTH satellite TV systems dedicated to the reception of a single satellite location in the sky, only two sets of wires are usually required: the coaxial cable from the LNB to the receiver, and a two or three conductor wire from the ferrite polarizer or servo motor of the feedhorn to the polarizer control connections on the back of the receiver. Satellite TV systems dedicated to the reception of multiple satellite locations in the sky also will require an additional four or five conductor wire from the actuator motor at the antenna to the control terminals on the back of the receiver or controller power supply.

The best way to acquire these wires is to use an all-in-one satellite cable. For rooftop or wall mount installations, this cable should be fixed to the wall of the house by metal clamps up to the point at which it penetrates the wall. For large dish installations placed at ground level, direct burial cables are available that can be put in a trench that lies below the frost line up to the point at which it enters the building.

Be usre to purchase more than enough cable to complete the run all the way from the feedhorn on the antenna, down the pole, into the building, up the wall, through the attic, and down an interior wall (which is not always, but often times, the case), while leaving enough left over to easily reach to the back of the receiver. It is possible, but not desirable, to splice an extra few feet onto the cable if you end up with an insufficient length.

Before connecting all of these cables, however, it may be preferable to use a short piece to connect the satellite receiver and a TV set to the outdoor electronics right out at the dish. Tracking adjustments can then be made to the antenna while viewing TV signals and watching the satellite receiver's signal level indicator. Alternatively, a portable signal meter or spectrum analyzer can be used for this purpose. Two people also can talk back and forth via walkie talkie or portable phone while one makes adjustments to the antenna and the other reports any change in video performance.

All-in-one satellite cable is available containing either one or two coaxial lines. A cable with two coaxial lines is essential if either a hybrid feed (which requires one Ku-band and one C-band LNB) or a dual Ku-band feed (which requires two separate Ku-band LNBs or a dual LNB) is part of the system under construction. It is advisable to purchase the direct burial cable with two coaxial lines even if only a single

LNB will be installed initially. The spare coaxial line will then be in place in the event that the system is ever upgraded or if problems occur with the primary coaxial line.

If there will be more than two LNBs at the antenna, separate coaxial lines must be installed for each one. For example, multiple receiver systems with feedhorns which support two Ku-band and one C-band LNB (or even two Ku-band and two C-band LNBs) will need multiple coaxial lines.

Coaxial Cable and Connectors

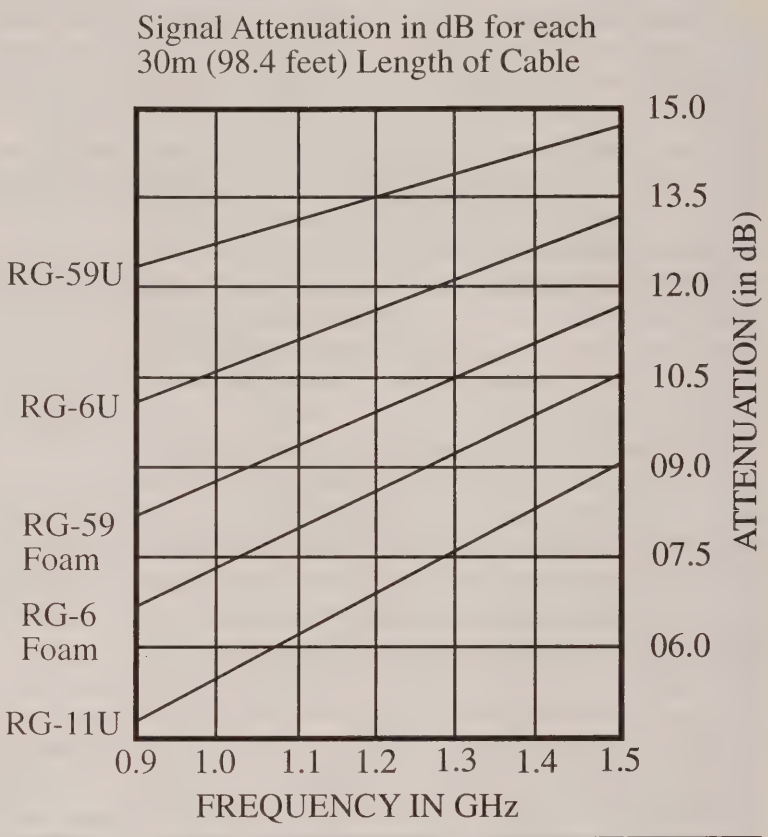
The type of cable used to connect the LNB and the receiver (or receivers in the case of SMATV systems) is called coax (from coaxial). Coax is made up of an inner wire covered with a plastic or foam sheath, and an outer mesh that is in turn surrounded by a waterproof plastic covering.

A single coaxial cable is used to transport the signal from the LNB to the indoor receiver. In many DTH installations, a shorter piece of coax also is used to connect the receiver to the antenna input on the TV.

A special type of cable TV connector, called an 'F' connector, is crimped onto each end of the coaxial cable. (A few of the satellite TV receivers manufactured in Europe alternatively use an "IEC" coax connector instead of the F connector.) This connector mates with complementary connectors on the LNB and indoor receiver. A special tool is used to crimp 'F' connectors onto the cable. Standard lengths of cable with the connectors already installed also can be purchased at local supply houses.

When screwing an F connector onto mating connectors on the back of the receiver or LNB, care should be taken to avoid bending or breaking the cable's inner conductor, thereby shorting out the connection. There also are right-angle F connectors which can be used whenever space limitations prevent a straight-on connection.

Fig. 8-15. Cable attenuation in dB per 30m (98.4 ft.) of cable.



The type of cable commonly used in satellite TV installations has a characteristic impedance rating of 75 ohms. The type of cable used by CB radios and other two-way radio equipment has a characteristic impedance rating of 50 ohms and is not suitable for satellite TV use.

Several different of 75 ohm coaxial cable are available. RG-59U coax can be used to span distances of up to 100 feet. For longer lengths, lower loss RG-6 or RG-11 are used. All-in-one satellite cable contains one or two spans of RG-6. Since RG-6 is slightly larger in diameter than RG-59, it also requires a slightly larger F connector. To span distances of several hundred feet, special UHF line amplifiers with +10 or +20 dB gain also may be necessary to compensate for the amount of signal loss or attenuation that occurs as the signal passes along the length of cable.

The power required to operate the LNB (and any associated line amplifiers which may be required for installations where the antenna is

several hundred feet from the indoor receiver) is supplied by the receiver and sent to the LNB via the center conductor of the coax cable. The power stays on even if the receiver is turned off. This keeps the LNB at a more consistent temperature and prevents moisture from condensing inside it. (This constant powering of the LNB also ensures that any decoder or IRD in the receiving system maintains continual access to the authorization data which encrypted programmers must deliver periodically to their subscribers' receiving systems.)

The receiver should be unplugged from the a.c. wall receptacle before connecting or disconnecting the coax cable from the LNB or the receiver. This eliminates the chance of a short circuit across the coaxial connections.

The connection to the LNB also should be weatherproofed to keep moisture out. This can be done by flooding the connector with a dielectric silicone sealer or wrapping the connection with a sticky wa-

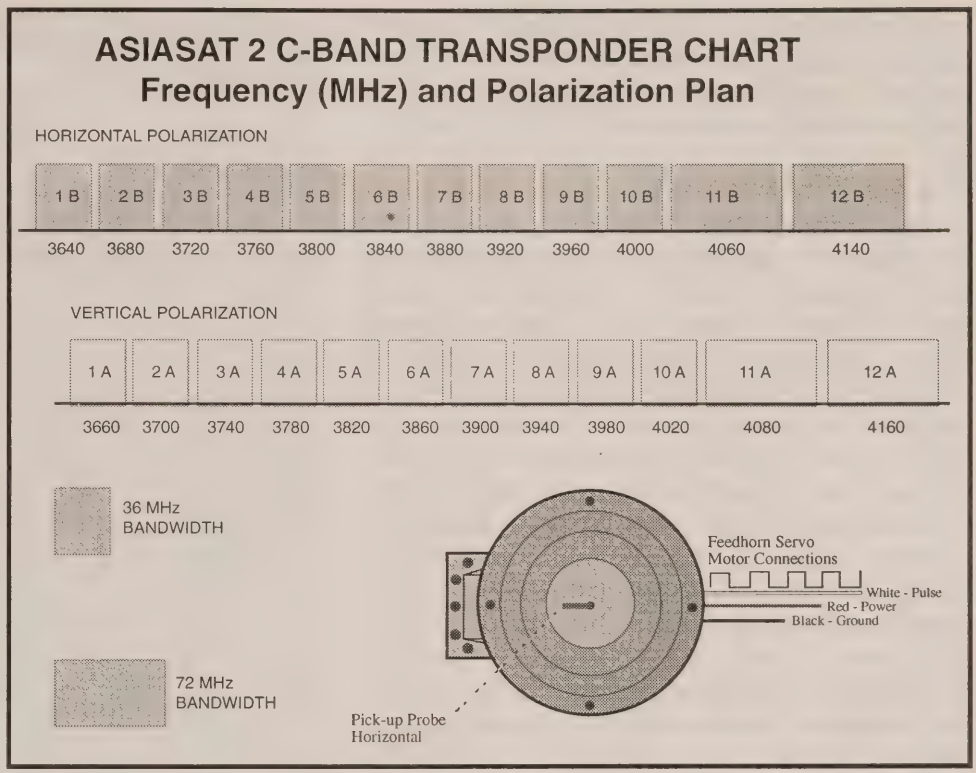

ASIASAT 2 C-BAND TRANSPONDER CHART
Frequency (MHz) and Polarization Plan
HORIZONTAL POLARIZATION
1 B 2 B 3 B 4 B 5 B 6 B 7 B 8 B 9 B 10 B 11 B 12 B
3640 3680 3720 3760 3800 3840 3880 3920 3960 4000 4060 4140
VERTICAL POLARIZATION
1 A 2 A 3 A 4 A 5 A 6 A 7 A 8 A 9 A 10 A 11 A 12 A
3660 3700 3740 3780 3820 3860 3900 3940 3980 4020 4080 4160
36 MHz BANDWIDTH
72 MHz BANDWIDTH
Feedhorn Servo Motor Connections
White - Pulse
Red - Power
Black - Ground
Pick-up Probe Horizontal

Fig. 8-16. Feedhorn skewed to receive AsiaSat 2 horizontal polarization signals from the author's site location in Chiang Mai, Thailand.

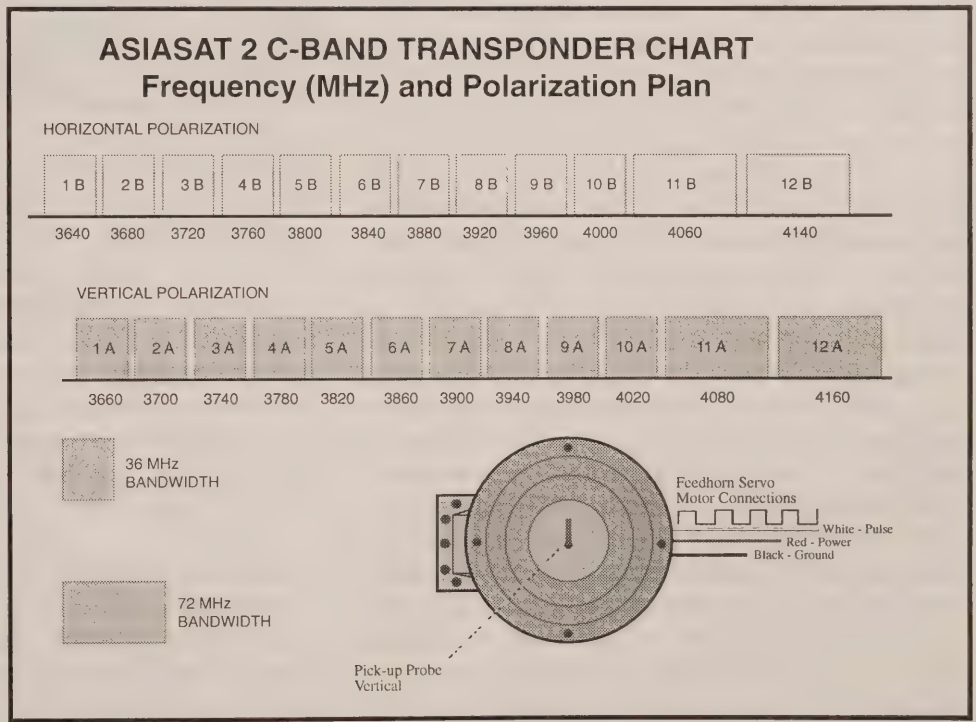

ASIASAT 2 C-BAND TRANSPONDER CHART
Frequency (MHz) and Polarization Plan
HORIZONTAL POLARIZATION
1 B 2 B 3 B 4 B 5 B 6 B 7 B 8 B 9 B 10 B 11 B 12 B
3640 3680 3720 3760 3800 3840 3880 3920 3960 4000 4060 4140
VERTICAL POLARIZATION
1 A 2 A 3 A 4 A 5 A 6 A 7 A 8 A 9 A 10 A 11 A 12 A
3660 3700 3740 3780 3820 3860 3900 3940 3980 4020 4080 4160
36 MHz BANDWIDTH
72 MHz BANDWIDTH
Feedhorn Servo Motor Connections
White - Pulse
Red - Power
Black - Ground
Pick-up Probe Vertical

Fig. 8-17. Feedhorn skewed to receive AsiaSat 2 vertical polarization signals from the author's site location in Chiang Mai, Thailand.

terproof compound such as Coax-Seal. It is also a good idea to use a plastic LNB cover to give your outdoor electronic components added protection from the elements.

Wiring the Feedhorn

The feedhorn line of the all-in-one cable is comprised of three color-coded 22 gauge (or larger) stranded wires. These wires also are shielded and jacketed. The three wires provide power, pulse, and ground connections for servo-motor type feedhorns. (Feedhorns with a ferrite polarizer will require just two wires.) Each of these wires connects to corresponding terminals on the back of the receiver. The wires are color-coded to help identify them when connecting to the three servo motor wires at the feed (usually red for power, white for pulse, and black for ground).

A stranded wire is used because it is more flexible and won't break as easily as a solid wire. The shield, an aluminum foil wrapped around all three wires, keeps impulse noises from entering the line and giving false pulses to the receiver. The receiver uses pulses to keep track of the position of the feedhorn's pick-up probe. The position of the probe therefore can be adjusted, or "skewed" and the optimum polarization programmed into receiver memory for any given satellite transponder.

The feedhorn's servo motor rotates the pick-up probe, which swings back and forth while switching between the horizontally and vertically (or right-hand and left-hand circularly) polarized transponders (odd and even channels on linearly-polarized satellites).

Keep in mind that there are limits to the pick-up probe's clockwise and counter-clockwise movements for servo motor type feedhorns. The feedhorn must be aligned on the antenna so that the probe can swing the 90 degrees from horizontal to vertical (or left-hand to right-hand circular) polarization without reaching the limits of its travel. Several manufacturers include a directional guide with their feedhorns to show the proper alignment of the feed when installed on the dish. If the probe is unable to skew beyond a good picture on both the odd and even channels on all satellites, loosen the clamp which holds the feed onto its support and physically rotate the feedhorn until it is possible to do so.

Wiring Actuators

For installations equipped with motorized antennas, the all-in-one cable's actuator line is comprised of five stranded wires. Two 14 or 16 gauge stranded wires are used to power the motor and three color-coded 22 gauge shielded wires connect to the sensor. These actuator wires should be connected to the appropriate terminals on the back of the receiver (or a separate actuator power supply).

Like the servo motor wires, the three shielded motor sensor wires also provide power, pulse, and ground. The vast majority of actuator motors do not require power to be hooked to the sensor. Look inside the actuator housing. If there are only two wires connected to the sensor, then hook up pulse and ground to their respective terminals. If there are three wires connected to the sensor, then connect the 5 volts from the receiver to the red wire on the actuator's sensor, and pulse and ground interchangeably to the other two sensor wires.

The two large stranded wires connect to the large wire terminals at the actuator motor and to the motor wire "1" and "2" terminals on the back of the receiver or power supply. Now try to move the dish to the East or West; if the dish moves in the direction opposite to the one intended, reverse the wires connected to the motor wire "1" and "2" terminals.

Some satellite receivers have an external power supply that puts the large transformer outside of the receiver chassis. This reduces the receiver's size as well as its operating temperature. The power supply is actually a large transformer that turns 120 or 240 volts a.c. into 24 to 36 volts d.c. to power the actuator's d.c. motor.

This outboard power supply can be placed behind the TV set or at some other out of the way place. Moreover, in a multi-receiver system only one power supply is needed because only one receiver can control the antenna's position. The receiver with the power supply is then called the "master" while any additional

Fig. 8-18. Some antenna manufacturers provide a calibrated scale whichprovide a reliable means for initially setting the angle of the modified polar mount as long as the mounting pole is plumb. (Photo by Mark Long).

receivers are called "slave" units.

Water intrusion can be a big problem with actuator motors. Be sure to run the wires through the rubber grommet supplied with the actuator to seal off the opening. Also mount the motor so the drain holes are on the bottom to allow any moisture to run out.

Grounding the System

If your building's a.c. electrical ground or "earth" is close to the dish, use a No. 10 AWG or larger solid copper ground wire to connect it to the pipe supporting the antenna. If the antenna is physically removed from the building, pound in a separate grounding rod and use a No. 10 AWG or larger solid copper ground wire to connect the pole to it. An antenna discharge unit or ground block, a passive electrical device that connects in-line between your outdoor electronics and the indoor satellite receiver, also should be installed. To work properly, the ground block should be connected to a ground rod or to the a.c. ground of the building.

For DTH systems—or any other TVRO system which does not require continual operation—there are additional precautions which can be taken to protect the system from possible lightning damage. For added protection prior to a lightning storm—or whenever the earth station is left unattended and unused for long periods of time—first unplug the satellite receiver from the a.c. wall outlet and then disconnect the incoming coaxial cable(s) from the IF input of the receiver. After the storm has passed, reconnect the coaxial cable to the receiver's IF input port before plugging the receiver back into the a.c. wall outlet. This will help prevent damage due to lightning or related power surges.

Quick disconnect adapters are available which permit rapid disconnection of all indoor components from the rest of the system. Surge protectors also should be used on the a.c. line connections to the satellite receiver and any connected components to prevent voltage surges or spikes from entering the system through the a.c. power connections.

Attaching the Actuator to the Antenna

Motorized dishes come with either a horizon to horizon mount or a mount which requires an actuator arm. For "horizon" mounts, the motorized housing will attach directly to a mating flange on the mount. Since there are several steps involved in installing motorized actuator arms, these steps will be described in detail. The principles related to setting the motor's programmable limits will be the same for either style mount.

Before installing the actuator arm, prop the dish up a few degrees with a block of wood or something else which won't damage the antenna. Attach the arm to the dish and the mount as indicated in the manufacturer's assembly directions. The arm attaches on the West side of the dish on systems located in

Eastern portion of the continent and on the East side of the dish on systems located in the Western portion of your continent. If the site location is somewhere in the middle of the continent, observe how existing actuator arms are mounted on existing systems in the area. (This is opposite for locations South of the Earth's equator.)

Refer to the Universal Azimuth-Inclination Look Angle chart presented inhe appendix to find the inclination angle for the satellite that is furthest to the West and furthest to the East of the site location. Before tightening the clamp which goes around the arm, use the inclinometer to read the inclination angle of the antenna. The arm is at its most retracted position when first installed. The antenna should be pointed just below the lowest satellite viewable from the site location when the arm is in this position. Prop the antenna at this inclination angle and then snug the clamp on the arm just enough to hold it in place.

Antenna Alignment Settings

At this point, it is best to connect the satellite receiver directly to the TV and not through a VCR, video switcher, splitter, or any other device. The appropriate receiver output connector for DTH systems will be labeled "To TV" or "RF OUT". On most receivers, the output signal can be switched between two or more VHF (or UHF for areas of the world where this is the predominant TV mode) channels. Select the VHF or UHF channel which is not in use locally and tune the TV set to receive the selected VHF or UHF channel.

At this point it is a good idea to follow the step-by-step procedures provided in the owner's manual. In most cases, the receiver also will prompt you with instructions that are displayed on the TV screen or on the receiver's front panel.

The first instruction most often provided by most DTH satellite receivers is to "Set East and West Limits". This is referring to the limits of travel for the actuator arm or horizon drive. Although the motor has a slip clutch to prevent damage when the arm is extended or retracted completely, it is best to set the receiver's programmable limits at positions before the arm reaches these points. Many motors come with built-in limit switches which will shut off the

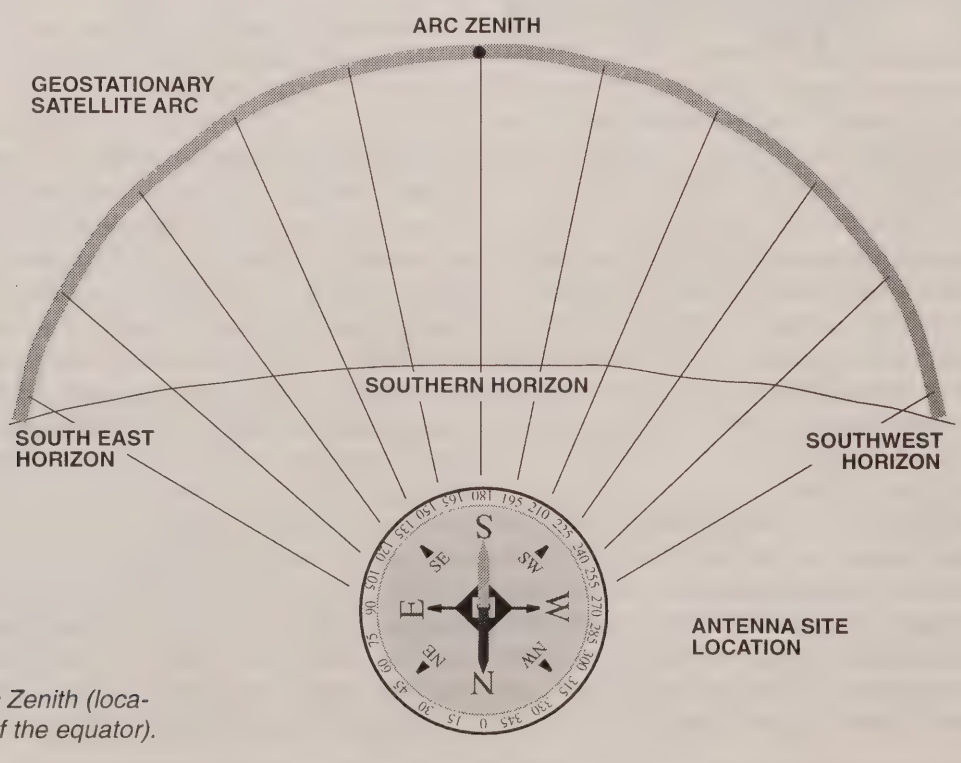


Fig.8-19. Arc Zenith (locations North of the equator).

Fig.8-20. Declination offset angles for sites in ITU Region 1—Europe, Africa and the Middle East.

N. or S LATITUDE	NEARBY CITY/REGION	POLAR AXIS ANGLE	ARC ZENITH	DECLINATION ANGLE
60	Oslo	60.59	68.06	7.46
59	Stockholm	59.61	67.00	7.38
53	Dublin	53.67	60.56	6.89
52	Rotterdam	52.68	59.48	6.80
50	Frankfurt	50.69	57.31	6.61
49	Paris	49.70	56.21	6.52
48	Munich	48.70	55.12	6.42
47	Berne	47.70	54.02	6.32
45	Belgrad	46.71	52.92	6.22
43	Florence	43.72	49.61	5.89
41	Naples	41.71	47.38	5.67
39	Lisbon	39.70	45.15	5.45
38	Athens	38.70	44.03	5.33
37	Tunis	37.69	42.90	5.21
35	Cyprus	35.68	40.65	4.97
32	Tel Aviv	32.66	37.25	4.59
30	Cairo	30.63	34.96	4.33
25	Riyadh	25.57	29.23	3.66
20		20.47	23.45	2.98
15		15.37	17.62	2.25
10		10.26	11.77	1.51
05		05.13	05.89	0.76
Equator	Libraville	0	0	0
05		05.13	05.89	0.76
10		10.26	11.77	1.51
15		15.37	17.62	2.25
18	Salisbury	18.44	21.12	2.68
20		20.47	23.45	2.98
25		25.57	29.23	3.66
26	Johannesburg	26.58	29.23	3.80
28		28.61	32.68	4.07
29		29.62	33.82	4.20
30		30.63	34.96	4.33
31		31.64	36.11	4.47
33		33.67	38.38	4.71
34	Cape Town	34.67	39.52	4.85
37		37.69	42.90	5.21
40		40.71	46.27	5.56

(IN DEGREES OF LATITUDE)

motor at designated points.

Setting the Programmable Limits

The East and West programmable limits for the DTH receiver (or the antenna controller for some large aperture TVRO systems) must be set to stop the travel of the arm or horizon drive before the built-in limit switches are engaged or before the drive's physical limits are reached. If the arm does reach its full length or is retracted completely the motor's slip clutch will start making loud "clicks". Stop immediately. If the arm becomes stuck in this position, take the motor off and insert the blade of a heavy screwdriver in the slot where the motor engages the arm. Turn the screw driver just enough to loosen the arm, then put the motor back in place.

The idea here is to set the limits so they are just past the last satellite at either end of the satellite arc but before the mechanical limits of the drive. Determine the inclination angles for the last satellite to the East and West, respectively, by using the chart previously provided.

It may occur that, after the system has begun to receive satellite TV signals, an insufficient

Fig.8-21. Declination offset angles for sites in ITU Region 2—The Americas.

N. or S. LATITUDE	NORTHERN CITY/REGION	POLAR AXIS ANGLE	ARC ZENITH	DECLINATION ANGLE
65	Fairbanks	65.52	73.32	7.80
60		60.59	68.06	7.47
55		55.66	62.72	7.06
54		54.67	61.64	6.97
53		53.67	60.56	6.89
52		52.68	59.48	6.80
51		51.69	58.39	6.70
50	Winnepeg	50.69	57.31	6.62
49	Western Border U.S./Canada	49.70	56.21	6.51
47	Duluth	47.70	54.02	6.32
45	Minneapolis	45.71	51.82	6.11
43	Milwaukee	43.72	49.61	5.89
41	Salt Lake City	41.71	47.38	5.67
40	Philadelphia	40.71	46.27	5.56
39	Kansas City	39.70	45.15	5.45
37	Norfolk	37.69	42.90	5.21
35	Albuquerque	35.68	40.65	4.97
33	Dallas	33.67	38.38	4.71
31		31.64	36.11	4.47
30	New Orleans	30.63	34.96	4.33
29		29.62	33.82	4.20
28	Tampa	28.61	32.68	4.07
26	Miami	26.58	30.38	3.80
20	Kona, Hawaii	20.47	23.45	2.98
15		15.37	17.62	2.25
10	Costa Rica	10.26	11.77	1.51
05	Bogota	05.13	05.89	0.76

(ALL ANGLES ARE IN DEGREES)

amount of room has been left to permit movement of the antenna past the last satellite at either end of the arc to ensure that maximum reception from that satellite has been obtained. In this case, the clamp on the actuator arm can be loosened and adjusted slightly to permit further travel.

An 18-inch actuator arm should be long enough for any 10-foot (3m) or smaller antenna and also most 12-foot (3.7m) antennas. Longer arms are available for larger dishes.

Check to see if the limits must be reset before programming in the locations of the individual satellites. Otherwise programming information previously programmed into the receiver will be deleted from memory prior to resetting the limits.

Setting the Antenna Polar Axis Elevation

Extend the drive until the antenna is looking at the highest point in the sky (arc zenith). Set the inclinometer onto the polar axis of the dish. Adjust the polar axis of the mount to the correct inclination angle for your location.

Setting the Declination

Declination is the offset angle between the polar axis of the mount and the rim of the antenna which permits the dish to precisely track the Clarke Orbit. The declination angle at any site is determined by the latitude at that location. The declination setting must be adjusted to the figure supplied by the manufacturer for your specific site. If you need to compute the declination you can find out the approximate value by using the charts for ITU Regions 1, 2, and 3 provided on the following pages.

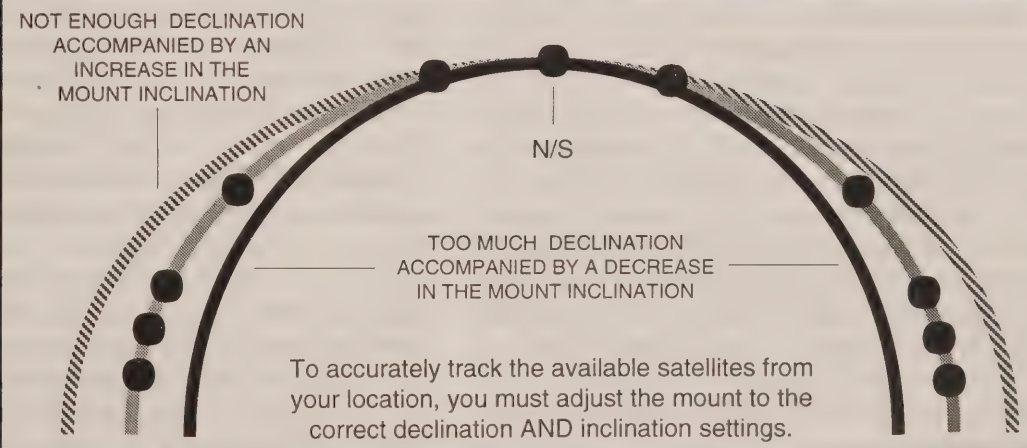
With a modified polar mount antenna, correct tracking of the entire portion of the Clarke Orbit viewable from the site location is only possible when the declination has been properly set. Set

Fig. 8-22. Declination offset angles for sites in ITU Region 3—The Asia/ Pacific.

N. or S LATITUDE	NEARBY CITY/REGION	POLAR AXIS ANGLE	ARC ZENITH	DECLINATION ANGLE
43	Vladivostok	43.72	49.61	5.89
41		41.71	47.38	5.67
40	Beijing, China	40.71	46.27	5.56
39		39.70	45.15	5.45
37	Seoul, Korea	37.69	42.90	5.21
35	Tokyo, Japan	35.68	40.65	4.97
33		33.67	38.38	4.71
31	Shanghai	31.64	36.11	4.47
30		30.63	34.96	4.33
29		29.62	33.82	4.20
28		28.61	32.68	4.07
25	Karatchi, PK	25.57	29.23	3.66
20	Haikou, China	20.47	23.45	2.98
15	Manila, PH	15.37	17.62	2.25
10	HCM City, VN	10.26	11.77	1.51
05	Brunei	05.13	05.89	0.76
Equator		0	0	0
05		05.13	05.89	0.76
10	Port Moresby	10.26	11.77	1.51
15		15.37	17.62	2.25
20		20.47	23.45	2.98
25		25.57	29.23	3.66
28	Brisbane, Aust.	28.61	32.68	4.07
29		29.62	33.82	4.20
30		30.63	34.96	4.33
31	Perth, Aust.	31.64	36.11	4.47
33	Sydney, Aust.	33.67	38.38	4.71
37	Auckland, NZ	37.69	42.90	5.21
40		40.71	46.27	5.56

(IN DEGREES OF LATITUDE)

Fig.8-23. Effects of declination adjustment.


NOT ENOUGH DECLINATION ACCOMPANIED BY AN INCREASE IN THE MOUNT INCLINATION
N/S
TOO MUCH DECLINATION ACCOMPANIED BY A DECREASE IN THE MOUNT INCLINATION
To accurately track the available satellites from your location, you must adjust the mount to the correct declination AND inclination settings.

the inclinometer on the back plate of the antenna (same plane as the rim of the dish). Using the declination adjustment on the mount, set the antenna for an inclination angle that is equal to the polar axis angle plus the number of degrees of declination for your area. The dish should be looking down slightly from the angle of the mount's polar axis.

Tracking Procedures

The next step in the installation process involves locating the correct antenna position

for each of the available satellites and programming these positions into the memory circuitry of the receiver or antenna controller. When moving the antenna to the East or West, the dish's look angle should now follow a curve similar to that of the Clarke Orbit.

DTH satellite receivers are now available which have been designed to locate and program the satellite locations into memory with a minimum of operator assistance. However, even these "smart" receivers will require the installer t o locate and identify one upper and one lower satellite. Automatic antenna peaking and polarity peaking features also are available on some DTH receivers. Before using these auto features, first follow the steps below to get the antenna to accurately track the Clarke Orbit. Turn on these auto features only after ensuring that best reception of the lower and upper satellite has been obtained.

The accuracy of these auto features primarily depends on the level of artifical intelligence built into the DTH receiver. Some of these receivers occasionally will miss one or more of the available. The practiced installer may find it simpler to peak the antenna position polarization settings manually.

Many DTH receivers provide a scanning feature that simplifies the location of satellites. These receivers scan repeatedly through all the available channels at a rapid pace, providing glimpses of the transponder video activity. Channels will flash by on the TV screen as the antenna is moving past a satellite. Go back to where the flashes occurred, turn off the scan feature, and identify the satellite according to its program lineup. Some satellites transmit a few channels of video. Without the scan feature, a known active video transponder and and its associated polarization setting would have to be selected before the satellite could be easily located.

Preview the sections in the receiver manual on antenna set-up and programming before initiating each of the following steps:

Inclinometer readings for the satellite look angles (the inclinations of the satellites available from the site location) should be taken on the back plate of the antenna or on a surface parallel to the plane of the rim of the dish.

1.) Determine the inclination of the lowest satellite available from the site location and move the antenna until the inclinometer registers that inclination.

2.) Engage the receiver's scan feature or set the receiver to a channel known to be carrying video programming. A 24 hour service, even if it is encrypted, would be a good choice. Refer to a current satellite TV program guide to find a suitable selection.

3.) Push the antenna to the right or left so that it rotates on the pole until a flash of video appears on the TV screen. Turn off the scan function and go through the channels until a video program has been found.

If the video seems to zip off the screen as soon as you stop on the channel, try changing the receiver's polarization format. That is, if the odd channels are set for vertical polarization and the even channels for horizontal, change the polarization format of the receiver to odds-horizontal, evens-vertical. A change in format changes the relationship of the feedhorn's pick-up probe by 90 degrees. If changing the format keeps the video on the screen, then it has to be the correct setting for that satellite on the TVRO system. Select the best skew setting for the odd and even channels and program it into memory. Most receivers have a LED signal level indicator on the front panel or a digital level indicator presented by on-screen graphics. The level indicator provides a better reading of peak satellite perfomance in contrast to just viewing the picture on the TV screen.

4.) For locating satellites in the lower section of the Clarke Orbit, manually push the antenna right and left on the pole and move the drive East and West in slight increments until satisfied that the strongest signal level has been obtained. Then snug the mount's bolts onto the pole so that the dish won't rotate. Do not tighten them down firmly yet, however. Note the numerical reading provided on the receiver's front panel or on-screen display which correspond to dish position at this location. This is a relative number that changes as the dish moves.

5.) Move the dish East or West until arc zenith

has been reached for the site location. Select an active transponder for the satellite closest to East or West of arc zenith or turn the scan control on. Then move the antenna in the direction of the nearest satellite until it has been acquired.

6.) For locating satellites that are in the upper section of the Clarke Orbit, jog the actuator drive East and West and adjust the inclination bracket (on the mount of the dish) up and down slightly. Adjustment of the inclintion setting should be minimal because it previously was pre-set for the site location. The rule of thumb here is: Rotate the dish on the pole and use the actuator to receive lower satellites, but do not rotate the dish on the pole to receive upper satellites. Adjust the elevation of the dish and use the actuator to receive upper satellites, but do not adjust the elevation to receive lower satellites.

7.) Fine tune tracking by repeating these steps until the satellites in both the upper and lower sections of the Clarke Orbit appear at their maximum signal strength without requiring any further adjustments. If this cannot be done, a miscalculation in the inclination or declination settings probably has been made. Once the antenna is tracking properly, firmly snug the bolts that secure the mount onto the pipe. Placing a bolt all the way through the pipe may be desirable in high wind areas. Mark the pole and the mount for later reference.

The Final Connection for DTH Systems

The final connection in DTH systems is from the satellite receiver to the TV set. It previously was mentioned that a coaxial cable can be connected directly from the "To TV" ("RF Out") output of the receiver to the "Antenna" input of the TV set. The local antenna wire, which formerly was connected directly to the TV set, should now be connected to the "Antenna" input on the back of the receiver. To watch local channels, turn the satellite receiver off and the local channels will automatically appear on their respective channels on the TV.

If the satellite receiver does not have this feature, purchase an A/B switch from a local satellite or electronics store. Both the satellite receiver and local antenna connect to the "A" and "B" input ports on this switch, while the single output port connects to the antenna input on the TV. This switch will have to be changed manually. An external A/B switch also may be necessary if a second TV is connected to the satellite receiver and one person wants to watch local TV while the other is watching a satellite TV program.

There are other options when it comes to connecting the satellite system to the TV set or home theater system. There are video and stereo audio outputs on the back of the receiver. These can be connected directly to a TV monitor or to a VCR for recording programs. Whenever a VCR is part of the overall entertainment system, the output of the VCR must be connected to the TV set and the local antenna connected to the "Antenna" input of the VCR.

The satellite receiver's stereo audio outputs can be connected directly to the stereo inputs of the TV set or to the auxiliary inputs of the stereo system's audio amplifier or tuner.

The SCART Connector

Developed by the French, the SCART (for Syndicat des Constructeurs d'Appareils Radio Recepteurs et Televisieurs) connector was developed in part as a standard for making connections between various audio and video products in the home entertainment system. The SCART connector, also known as the Peritel or Euro-Connector, subsequently was adopted as the standard audio/video interface connector by most countries in Western Europe.

One or more SCART connectors are now found on all satellite receivers, IRDs, and decoders manufactured for the European market. What's more, all TV sets sold in the Euro-

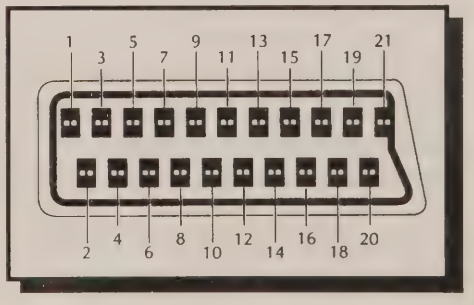


Fig. 8-24. A SCART Connector.

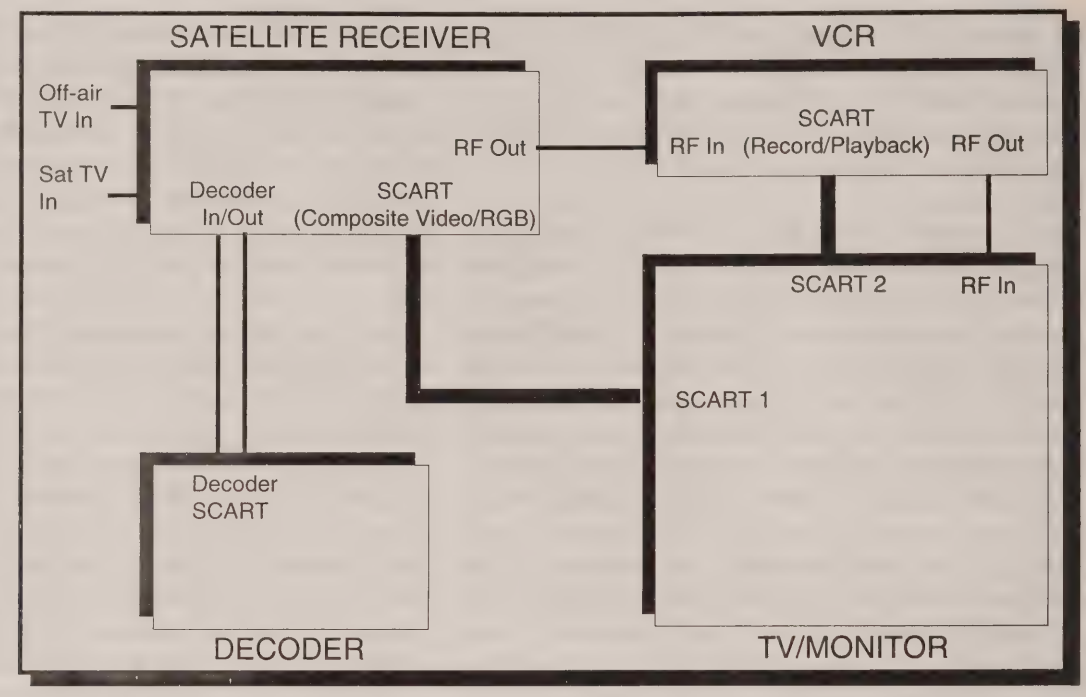


Fig. 8-26. Possible wiring connections between a satellite TV receiver, decoder, VCR and TV/Monitor.

pean market have one, two, or even three SCART connectors! The SCART connection is advantageous for displaying video of the best possible quality on top-of-the-line TV sets. The TV output of the satellite receiver is available in three modes: RF (for connection to the TV set's or VCR's UHF antenna jack), composite video (for connection to the video input or SCART connector of a VCR or TV/monitor's video input jack), or RGB (Red-Green-Blue plus synch)—for connection to the separate R, G, & B circuits within the TV set or TV monitor. The SCART connector can supply both composite video and RGB plus synch. Since a direct RGB connection can made between the satellite TV receiver, VCR, and TV, the visual imperfections associated with composite video are eliminated.

SCART control centers and splitters with stereo audio output connectors also are available to enable TV audio sound to be played through your home's hi-fi entertainment system. The following block diagrams show the pin configuration of the SCART connector and the possible wiring connections for a home entertainment system equipped with a satellite IRD, VCR, and TV.

Fig. 8-25. SCART Connector pin configuration. Note that pins 10 and 12 are used for interfacing peripheral equipment by transferring control data from the host equipment to the peripheral devices.

1 Right Audio Out
2 Right Audio In
3 Left Audio Out
4 Audio Earth
5 Blue Earth
6 Left Audio In
7 Blue In
8 Source Switching
9 Green Earth
10 Intercommunication
11 Green In
12 Intercommunication
13 Red Earth
14 Intercommunication Earth
15 Red In
16 Fast RGB Blanking
17 Earth for composite video, synch & blanking
18 Fast blanking Earth
19 Composite Video out
20 Composite Video in
21 Socket Earth

Chapter 9

Modified Polar Mount Installations

Satellite Antenna Mount Alignment

by Jim Roberts

Precise pointing of satellite dishes and the tenacious holding of that position are dependent on the mount. Due to the decreased beamwidth of Ku-band dishes and large aperture C-band dishes, the mount must be rigid enough to maintain a precise position once it has acquired a satellite. A one-half inch movement of the lip of a 5-foot dish or a one inch movement of a ten-foot dish results in a full degree movement in the dish's direction. Thus movements of a fraction of an inch can make the difference between excellent reception and no reception at all. The dish must remain precisely pointed, even during bad weather conditions. The mount also acts as the main means of support for the parabolic reflector. Surface accuracy depends in part on the support that the mount gives to the dish. Flexing can occur if the mount does not adequately distribute stress which impinges on the dish from wind loadings, as well as the thermal effects of sun/shadow and the ever-present pull of gravity.

Az/El Mounts

Direction to a satellite from an earth station site typically is expressed as "Azimuth", the angular amount East, or West, in the site's "horizontal plane", and "Elevation", the angular amount up from the site's horizon. Methods for calculation or interpolation of these angles are provided on pages 134 through 137 and two simple computer programs are provided on page 144.

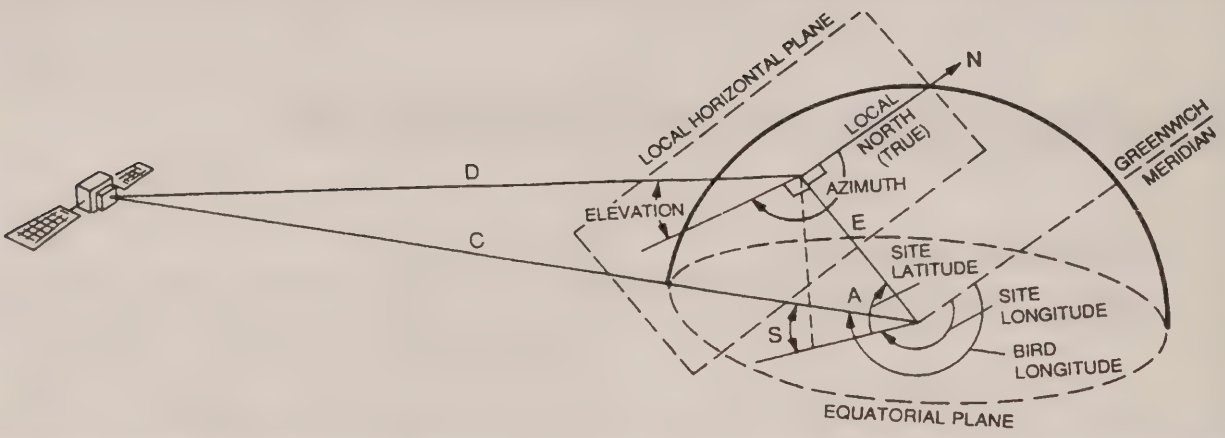
The local site's horizontal plane is the flat plane passing through the observer's location on the Earth's surface. Relative to this plane, horizontal means in (or parallel to) this plane and vertical means perpendicular to it, with "down" a motion toward the center of the Earth.

Az/El (Azimuth/Elevation) mounts hold their dishes in the East/West and tipped back/upward directions required to receive signals from a geostationary satellite. Automating Az/El mounts for remote controlled change in satellite selection requires two motors to move the dish and a third motor (or other means) to rotate the feed's orientation to compensate for the "skew" of linearly polarized satellite signals.

The feeds on Az/El mount dishes require skew correction for peak reception of linear polarized satellite signals. The Az/El dish feed's "horizontal/vertical" orientation is relative to the site's horizontal plane, while the satellites' "horizontal/vertical" orientation is relative to the "equatorial plane".

The Earth's equatorial plane is the flat plane passing through the Earth at its equator and extending out into space. Relative to this plane, horizontal means in (or parallel to) the equatorial plane and vertical means perpendicular to it. Vertical also means parallel to the Earth's rotational pole which is perpendicular to the equatorial plane. The perspective of the satellites' orientation rotates, or "skews", relative to the site's horizontal plane, for satellites East or West of the site. Feeds with variable polarizers for alternating horizontal/vertical selection can correct for skew with their variability. Feeds with fixed linear polarization must be physi-

Fig 9-1. Azimuth & Elevation Angle Derivation



Azimuth and Elevation Angle Derivation

Calculation of the angles of Elevation and Azimuth, looking from any site on Earth to a communications satellite requires two constants, two variables, an intermediate equation, and two final equations using trigonometry values. It can be done manually, with the following equations and values:

Constants: E = 3959 (Earth mean radius)
C = 26200 (Clarke Orbit radius)

Variables: A = Antenna site Latitude
S = Satellite Longitude minus Antena Site Longitude

Intermediate calculation
(Distance between Satellite & Antenna Site):

$$D = [[C*\mathrm{Cos}(S) - E*\mathrm{Cos}(A)]^2 + [C*\mathrm{Sin}(S)]^2 + [E*\mathrm{Sin}(A)]^2]^{1/2}$$

Final calculations of Azimuth and Elevation Values:

$$\mathrm{Azimuth} = \mathrm{ArcTan}[\mathrm{Tan}(S)/\mathrm{Sin}(A)] + 180$$
(For sites in Northern Hemisphere)
$$\mathrm{Elevation} = \mathrm{ArcCos}\ ((D^2 + E^2 - C^2)\ /2*D*E)\ - 90$$

cally rotated relative to the local horizontal/vertical.

The "Polar" Mount

"Polar" mounts track the satellites along the geostationary arc by means of the single adjustment of rotation about their axes called the "actuation", and only require one motor. For centuries, astronomers have mounted their telescopes on a "True Polar Mount" which has an axis that is fixed precisely parallel to the Earth's pole of rotation. The orientation of the "True Polar Mount" axis works out with geometric precision to be in line with True North-South and inclined to the exact angular magnitude of the local Latitude.

Angle	Sin	Cos	Angle	Angle	Sin	Cos	Angle
01	.01745	.99985	89	24	.40674	.91355	66
02	.03490	.99939	88	25	.42262	.90631	65
03	.05234	.99863	87	26	.43837	.89879	64
04	.06976	.99756	86	27	.45399	.89101	63
05	.08716	.99619	85	28	.46947	.88295	62
06	.10453	.99452	84	29	.48481	.87462	61
07	.12187	.99255	83	30	.50000	.86603	60
08	.13917	.99027	82	31	.51504	.85717	59
09	.15643	.98769	81	32	.52992	.84805	58
10	.17365	.98481	80	33	.54464	.83867	57
11	.19081	.98163	79	34	.55919	.82904	56
12	.20791	.97815	78	35	.57358	.81915	55
13	.22495	.97437	77	36	.58779	.80902	54
14	.24912	.97030	76	37	.60182	.79864	53
15	.25882	.96593	75	38	.61566	.78801	52
16	.27564	.96126	74	39	.62932	.77715	51
17	.29237	.95630	73	40	.64279	.76604	50
18	.30902	.95106	72	41	.65606	.75471	49
19	.32557	.94552	71	42	.66913	.74313	48
20	.34202	.93969	70	43	.68200	.73135	47
21	.35837	.93353	69	44	.69466	.71934	46
22	.37461	.92718	68	45	.70711	.70711	45
23	.39073	.92050	67				

Fig. 9-2. Trigonometry Values (Note: Tan = Sin/Cos; & ArcCos(Tan) is the ANGLE for that Cos(Tan) decimal value.)

The Modified Polar Mount

The astronomer's True Polar Mount was taken by many early satellite system designers as the exact model for satellite mount installations. Unlike the astronomer's celestial targets—which are very far away and therefore effectively at infinity—geostationary satellites are only 22,000 to 27,000 miles from any site on Earth. Because of the relative closeness of these man-made objects, the satellite mount axis must be inclined a fraction of a degree toward the Equator from parallel to the polar axis of the Earth. It is this non-parallelism which calls for the quotation marks surrounding the word "Polar", or the title "Modified" preceding the word polar in technically correct descriptions of the satellite system's mount. This fraction of a degree is the difference between LAT and MOUNT AXIS values.

Objects in the geostationary arc or "Clarke Orbit"—a circle in the Earth's "equatorial plane" with a radius from the Earth's center of 26,200.1 statute miles—orbit the Earth with a rotational speed which exactly matches the Earth's daily rotational speed, and thus when viewed from any site on Earth appear to occupy fixed points in the sky.

To observe the Clarke Orbit, satellite dishes are tipped from their mounts' modified axes toward the equator by a small angle which is called the "declination". Since the dish is only tracking the Clarke Orbit, where the geostationary satellites are located, its declination does not have to be changed after installation

INCLINATION (COMPLEMENT OF ELEVATION) TABLE

Longitude Difference between your location and the satellite which you seek:

LAT.	0	10	20	25	30	35	40	45	50	55	60	65	70
00	0	11.77	23.45	29.23	34.97	40.65	46.27	51.82	57.31	62.72	68.06	73.32	78.52
05	5.89	13.14	24.13	29.77	35.40	41.00	46.56	52.06	57.50	62.88	68.19	73.43	78.60
10	11.77	16.58	26.08	31.31	36.65	42.03	47.41	52.77	58.10	63.37	68.59	73.75	78.84
15	17.62	21.08	29.02	33.72	38.64	43.69	48.80	53.94	59.07	64.17	69.24	74.27	79.25
20	23.45	26.08	32.67	36.80	41.25	45.90	50.67	55.51	60.39	65.27	70.15	74.99	79.81
25	29.23	31.31	36.80	40.39	44.35	48.57	52.96	57.46	62.04	66.65	71.28	75.91	80.51
26	30.38	32.37	37.67	41.16	45.02	49.15	53.46	57.89	62.40	66.96	71.54	76.11	80.67
27	31.53	33.44	38.55	41.94	45.71	49.75	53.98	58.34	62.78	67.28	71.80	76.32	80.84
28	32.68	34.51	39.44	42.73	46.41	50.36	54.51	58.79	63.17	67.60	72.07	76.54	81.01
29	38.32	35.58	40.34	43.54	47.12	50.98	55.05	59.26	63.57	67.94	72.35	76.77	81.18
30	34.96	36.65	41.25	44.35	47.84	51.62	55.60	59.74	63.98	68.29	72.63	77.00	81.36
31	36.11	37.72	42.17	45.18	48.58	52.26	56.17	60.23	64.40	68.64	72.93	77.24	81.55
32	37.25	38.80	43.09	46.01	49.32	52.96	56.74	60.73	64.83	69.00	73.23	77.48	81.74
33	38.38	39.88	44.02	46.86	60.08	53.59	57.33	61.24	65.27	69.38	73.54	77.73	81.94
34	39.52	40.95	44.96	47.71	50.84	54.27	57.93	61.76	65.72	69.76	73.86	77.99	82.14
35	40.65	42.03	45.90	48.57	51.62	54.96	58.54	62.29	66.17	70.15	74.18	78.25	82.34
36	41.78	43.11	46.84	49.43	52.40	55.66	59.16	62.83	66.64	70.54	74.51	78.52	82.55
37	42.90	44.19	47.80	50.31	53.91	56.37	59.78	63.38	67.11	70.95	74.85	78.80	82.77
38	44.03	45.26	48.75	51.19	53.99	57.08	60.42	63.94	67.60	71.36	75.20	79.08	82.99
39	45.15	46.34	49.71	52.07	54.79	57.81	61.06	64.50	68.09	71.78	75.66	79.37	83.22
40	46.27	47.41	50.67	52.96	55.60	58.54	61.71	65.08	68.59	72.21	75.91	79.66	83.44
41	47.38	48.49	51.63	53.85	56.42	59.28	62.37	65.66	69.09	72.64	76.27	79.96	83.68
42	48.50	49.56	52.60	54.75	57.24	60.02	63.04	66.25	69.61	73.08	76.64	80.26	83.92
43	49.61	50.63	53.57	55.65	58.07	60.77	63.71	66.85	70.13	73.53	77.02	80.57	84.16
44	50.72	51.70	54.54	56.55	58.90	61.53	64.39	67.45	70.66	73.98	77.40	80.88	84.41
45	51.82	52.77	55.51	57.46	59.74	62.29	65.08	68.06	71.19	74.44	77.79	81.20	84.66
46	52.92	53.84	56.49	58.37	60.58	63.06	65.77	69.67	71.73	74.91	78.18	81.52	84.91
47	54.02	54.91	57.46	59.29	61.42	63.83	66.47	69.29	72.27	75.38	78.58	81.85	85.17
48	55.12	55.97	58.44	60.20	62.27	64.61	67.17	69.92	72.83	75.86	78.98	82.18	85.43
49	56.21	57.04	59.41	61.12	63.12	65.39	67.88	70.55	73.38	76.34	79.39	82.52	85.70
50	57.31	58.10	60.39	62.04	63.98	66.17	68.59	71.19	73.94	76.83	79.81	82.86	85.97
51	58.39	59.16	61.37	62.96	66.96	64.84	69.30	71.83	74.51	77.32	80.22	83.21	86.24
52	59.48	60.21	62.34	63.88	65.69	67.75	70.02	72.48	75.08	77.81	80.65	83.55	86.52
53	60.56	61.27	63.32	64.80	65.56	68.55	70.75	73.13	75.66	78.32	81.07	83.91	86.80
54	61.64	62.32	64.30	65.73	67.42	69.35	71.48	73.78	76.24	78.82	81.50	84.26	87.06
55	62.72	63.37	65.27	66.65	68.29	70.15	72.21	74.44	76.83	79.33	81.94	84.62	87.37
56	63.79	64.42	66.25	67.85	69.15	70.95	72.94	75.11	77.41	79.85	82.38	84.99	87.66
57	64.86	65.46	67.23	68.50	70.02	71.75	73.68	75.77	78.01	80.36	82.82	85.35	87.95
58	65.93	66.51	68.20	69.43	70.89	72.56	74.42	76.44	78.60	80.89	83.27	85.73	88.24
59	67.00	67.55	69.17	70.36	71.76	73.37	75.16	77.11	79.20	81.41	83.72	86.10	88.54
60	68.06	68.59	70.15	71.28	72.63	74.18	75.91	77.79	79.81	81.94	84.17	86.48	88.84
65	73.32	73.75	74.99	75.91	77.00	78.25	79.66	81.20	82.86	84.62	86.48	88.40	
70	78.52	78.84	79.81	80.51	81.36	82.34	83.44	84.66	85.97	87.37	88.84		
75	83.64	83.87	84.58	85.09	85.71	86.43	87.25	88.14	89.11				
80	88.69	88.84	89.30	89.64									

Fig. 9-3. Inclination Table. It is often easier to measure the tangible dish slope, rather than the intangible line of elevation towards the satellite. As long as the dish is a symmetrical center-fed parabola, these slopes will guide you.

unless the particular satellite being tracked is in an "inclined orbit". (See Chapter 10 for further information on inclined orbit satellites.)

A dish attached to a Modified Polar Mount and set for the correct declination can be turned or "actuated" around its axis to sweep the circular Clarke Orbit with a sector of its

AZIMUTH TABLE

Longitude Difference between your location and the satellite which you seek:

LAT.	0	10	20	25	30	35	40	45	50	55	60	65	70
00	0	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00
05	0	63.70	76.53	79.41	81.42	82.90	84.07	85.02	85.82	86.51	87.12	87.67	88.18
10	0	45.44	64.49	69.58	73.26	76.07	78.31	80.15	81.71	83.07	84.27	85.37	86.38
15	0	34.27	54.58	60.97	65.85	69.71	72.86	75.49	77.75	79.73	81.50	83.12	84.62
20	0	27.27	46.78	53.74	59.36	63.97	67.82	71.12	73.99	76.53	78.83	80.94	82.90
25	0	22.65	40.74	47.81	53.80	58.89	63.27	67.09	70.47	73.52	76.29	78.85	81.26
26	0	21.91	39.70	46.77	52.79	57.95	62.42	66.33	69.80	72.94	75.80	78.45	80.93
27	0	21.23	38.72	45.77	51.82	57.04	61.58	65.58	69.15	72.37	75.31	78.05	80.62
28	0	20.59	37.79	44.81	50.88	56.16	60.77	64.85	68.50	71.80	74.83	77.65	80.30
29	0	19.99	36.90	43.89	49.98	55.30	59.98	64.14	67.86	71.25	74.36	77.26	79.99
30	0	19.43	36.05	43.00	49.11	54.47	59.21	63.43	67.24	70.70	73.90	76.88	79.69
31	0	18.90	35.25	42.16	48.26	53.66	58.46	62.75	66.63	70.17	73.44	76.50	79.38
32	0	18.40	34.48	41.35	47.45	52.88	57.73	62.08	66.03	69.64	72.99	76.12	79.08
33	0	17.94	33.75	40.57	46.67	52.12	57.01	61.43	65.44	69.13	72.54	75.75	78.79
34	0	17.50	33.06	39.82	45.92	51.39	56.32	60.79	63.86	68.62	72.11	75.39	78.50
35	0	17.09	32.40	39.11	45.19	50.68	55.64	60.16	64.30	68.12	71.68	75.03	78.21
36	0	16.70	31.77	38.43	44.49	49.99	54.99	59.55	63.75	67.63	71.25	74.67	77.92
37	0	16.33	31.17	37.77	43.81	49.32	54.35	58.96	63.21	67.15	70.84	74.32	77.64
38	0	15.98	30.59	37.14	43.16	48.68	53.73	58.38	62.68	66.68	70.43	73.98	77.37
39	0	15.65	30.04	36.54	42.53	48.05	53.13	57.82	62.16	66.22	70.03	73.65	77.10
40	0	15.34	29.52	35.96	41.93	47.45	52.55	57.27	61.66	65.77	69.64	73.31	76.83
41	0	15.04	29.02	35.40	41.35	46.86	51.98	56.73	61.17	65.33	69.25	72.99	76.57
42	0	14.76	28.54	34.87	40.79	46.30	51.43	56.21	60.69	64.90	68.88	72.67	76.31
43	0	14.50	28.09	34.36	40.25	45.75	50.90	55.71	60.22	64.47	68.51	72.36	76.06
44	0	14.24	27.65	33.87	39.73	45.23	50.38	55.21	59.76	64.06	68.15	72.05	75.81
45	0	14.00	27.24	33.40	39.23	44.72	49.88	54.74	59.32	63.66	67.79	71.75	75.57
46	0	13.77	26.84	32.95	38.75	44.23	49.39	54.27	58.88	63.27	67.45	71.46	75.33
47	0	13.56	26.46	32.52	38.29	43.75	48.92	53.82	58.46	62.88	67.11	71.17	75.09
48	0	13.35	26.09	32.11	37.84	43.30	48.47	53.38	58.05	62.51	66.78	70.89	74.86
49	0	13.15	25.75	31.71	37.42	42.85	48.03	52.96	57.65	62.15	66.46	70.61	74.64
50	0	12.96	25.41	31.33	37.00	42.43	47.61	52.55	57.27	61.79	66.14	70.34	74.42
51	0	12.78	25.10	30.96	36.61	42.02	47.20	52.15	56.89	61.45	65.83	70.08	74.21
52	0	12.61	24.79	30.62	36.23	41.62	46.80	51.76	56.53	61.11	65.54	69.82	74.00
53	0	12.45	24.50	30.28	35.86	41.24	46.42	51.39	56.17	60.79	65.25	69.57	73.79
54	0	12.30	24.22	29.96	35.51	40.88	46.05	51.03	55.83	60.47	64.96	69.33	73.59
55	0	12.15	23.96	29.65	35.18	40.52	45.69	50.68	55.50	60.16	64.69	69.09	73.40
56	0	12.01	23.70	29.36	34.85	40.18	45.35	50.34	55.18	59.86	64.42	68.86	73.21
57	0	11.87	23.46	29.07	34.54	39.86	45.01	50.01	54.86	59.58	64.16	68.64	73.03
58	0	11.75	23.23	28.80	34.25	39.55	44.70	49.70	54.56	59.30	63.91	68.42	72.85
59	0	11.62	23.01	28.55	33.96	39.24	44.39	49.40	54.27	59.03	63.67	68.21	72.67
60	0	11.51	22,80	28.30	33.69	38.96	44.10	49.11	53.99	58.77	63.43	68.01	72.50
65	0	11.01	21.88	27.23	32.50	37.69	42.79	47.81	52.75	57.60	62.38	67.09	
70	0	10.63	21.17	26.39	31.57	36.69	41.76	46.78	51.74	56.66	61.52		
75	0	10.35	20.65	25.77	30.87	35.94	40.98	45.99	50.97				
80	0	10.15	20.28	25.34									

Fig. 9-4. Azimuth Table. The following angular values represent the number of degrees, measured in the dish site's local horizontal plane, to find satellites with Longitudes West (or East) of the dish site's Longitude. For True Bearings to satellites West of Northern Hemispheric sites, you add these values to 180. For satellites East of Northern Hemispheric sites, subtract these values from 180. From sites in the Southern Hemisphere, Western (or Eastern) satellites' True Bearings result from subtracting from (or adding to) 360/0. For compass bearings, you must correct True Bearings by adding any local Western (subtracting Eastern) Magnetic Error.

SKEW TABLE

Longitude Difference between your location and the satellite which you seek:

LAT.	0	10	20	25	30	35	40	45	50	55	60	65	70
00	0	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00
05	0	63.26	76.53	78.30	80.08	81.33	82.25	82.95	83.48	83.90	84.23	84.49	84.68
10	0	44.56	64.49	67.35	70.57	72.91	74.66	76.00	77.04	77.85	78.49	78.99	79.37
15	0	32.95	54.58	57.62	61.81	64.96	67.37	69.25	70.72	71.89	72.81	73.53	74.08
20	0	25.51	46.78	49.26	53.95	57.60	60.48	62.76	64.59	66.04	67.20	68.12	68.83
25	0	20.42	40.74	42.19	47.00	50.89	54.04	56.60	58.67	60.35	61.70	62.77	63.61
26	0	19.60	35.04	40.91	45.71	49.62	52.81	55.40	57.52	59.23	60.61	61.71	62.57
27	0	18.82	33.87	39.67	44.46	48.38	51.60	54.22	56.37	58.12	59.53	60.66	61.53
28	0	18.09	32.75	38.48	43.24	47.17	50.40	53.06	55.24	57.01	58.45	59.60	60.50
29	0	17.39	31.68	37.32	42.05	45.98	49.23	51.91	54.11	55.91	57.38	58.55	59.48
30	0	16.74	30.64	36.20	40.89	44.81	48.07	50.77	53.00	54.82	56.31	57.50	58.43
31	0	16.12	29.65	35.12	39.77	43.67	46.93	49.64	51.89	53.74	55.25	56.46	57.40
32	0	15.53	28.69	34.07	38.67	42.56	45.81	48.53	50.80	52.66	54.19	55.42	56.38
33	0	14.97	27.77	33.06	37.59	41.45	44.71	47.44	49.71	51.59	53.13	54.38	55.35
34	0	14.44	26.89	32.07	36.65	40.38	43.62	46.35	48.64	50.53	52.09	53.34	54.33
35	0	13.93	26.03	31.11	35.53	39.32	42.55	45.28	47.57	49.48	51.04	52.31	53.31
36	0	13.44	25.21	30.19	34.54	38.29	41.50	44.22	46.52	48.43	50.01	51.28	52.29
37	0	12.98	24.41	29.29	33.57	37.28	40.46	43.18	45.47	47.39	48.97	50.26	51.27
38	0	12.53	23.64	28.41	32.62	36.28	39.45	42.15	44.44	46.36	47.94	49.24	50.26
39	0	12.10	22.90	27.56	31.69	35.31	38.44	41.13	43.41	45.33	46.92	48.22	49.25
40	0	11.69	22.18	26.73	30.79	34.36	37.45	40.12	42.39	44.31	45.90	47.21	48.24
41	0	11.30	21.48	25.93	29.91	33.42	36.48	39.13	41.39	43.30	44.89	46.19	47.23
42	0	10.92	20.80	25.14	29.04	32.50	35.52	38.14	40.39	42.29	43.89	45.19	46.22
43	0	10.55	20.14	24.38	28.20	31.60	34.58	37.17	39.40	41.30	42.88	44.18	45.22
44	0	10.19	19.50	23.64	27.37	30.71	33.65	36.21	38.42	40.31	41.89	43.18	44.22
45	0	09.85	18.88	22.91	26.57	29.84	32.73	35.26	37.45	39.32	40.89	42.19	43.22
46	0	09.52	18.28	22.20	25.77	28.98	31.83	34.33	36.49	38.35	39.91	41.19	42.22
47	0	09.20	17.69	21.51	25.00	28.14	30.94	33.40	35.54	37.38	38.92	40.20	41.23
48	0	08.89	17.12	20.83	24.24	27.31	30.06	32.48	34.60	36.41	37.95	39.22	40.23
49	0	08.58	16.56	20.17	23.49	26.50	29.20	31.58	33.66	35.45	36.97	38.23	39.24
50	0	08.29	16.01	19.53	22.76	25.70	28.34	30.68	32.73	34.50	36.01	37.25	38.26
51	0	08.00	15.48	18.89	22.04	24.91	27.50	29.80	31.81	33.56	35.04	36.28	37.27
52	0	07.73	14.96	18.27	21.34	24.14	26.67	28.92	30.90	32.62	34.08	35.30	36.28
53	0	07.45	14.45	17.66	20.65	23.38	25.84	28.05	30.00	31.69	33.13	34.33	35.30
54	0	07.19	13.95	17.07	19.96	22.62	25.03	27.19	29.10	30.76	32.18	33.36	34.32
55	0	06.93	13.47	16.48	19.30	21.88	24.23	26.34	28.21	29.84	31.23	32.40	33.34
56	0	06.68	12.99	15.91	18.64	21.15	23.44	25.50	27.33	28.92	30.29	31.44	32.37
57	0	06.43	12.52	15.35	17.99	20.43	22.66	24.66	26.45	28.01	29.35	30.48	31.39
58	0	06.19	12.06	14.79	17.35	19.72	21.88	23.84	25.58	27.11	28.42	29.52	30.42
59	0	05.96	11.61	14.25	16.72	19.02	21.12	23.02	24.72	26.21	27.49	28.57	29.45
60	0	05.73	11.17	13.71	16.10	18.32	20.36	22.21	23.86	25.31	26.57	27.62	28.48
65	0	04.63	09.06	11.15	13.12	14.97	16.69	18.25	19.66	20.91	21.99	22.91	
70	0	03.62	07.10	08.74	10.31	13.17	14.43	15.58	16.60	17.50			
75	0	02.66	05.24	06.46	07.63	08.74	09.77	10.73	11.60				
80	0	01.75	03.45	04.26									

Fig. 9-5. Skew Values for Site Latitude & Longitude Difference. The above angular values represent Skew (perspective change). The feed rotation is counter-clockwise, looking over the feed into the dish, for satellites East of Northern Hemisphere sites; and clockwise for satellites to the West. Opposite rotation in Southern Hemisphere.[Skew=ArcTan(Sin(S)/Tan(A)) with A & S defined in Fig. 9-1].

elliptical, "look direction" curve that acquires each satellite to within a few thousandths of a degree—well within the stationkeeping accuracy of most mechanical mount mechanisms.

Skew Compensation Within "Polar" Mount Articulation

The orientation of a feed attached to a "Polar" mounted dish is relative to the line of the "Polar" axis, which is perpendicular to the Equatorial plane for all practical purposes. The horizontal/vertical orientation of linearly polarized signals from the satellites is relative to that same Equatorial plane. There is no need for the skew correction (which movement on the Az/El mount needs) when a "Polar" mounted dish is moved toward satellites to the East, or West, of the earth station.

Polar Alignment History/Background

Although U.K. satellite TV pioneer Stephen J. Birkill explained the need to modify axis inclination of the satellite mount by what he called "the A Factor" way back in the late 1970s, most early satellite TV enthusiasts ignored this subtlety and embraced the easier-to-describe "True" Polar Mount. Installation instructions were widely published erroneously prescribing inclination of the axis to match the local Latitude, with tables of excessive declination values based on subtracting the Latitude from the total elevation angle required for the highest part of the satellite arc. Some dish manufacturers realized that setting declination to match the single elevation angle to the top of the arc was not as helpful as setting declination to an average/compromise elevation of at least two elevation angles to the locally visible satellite arc. Publication of different declination values thus exist in various installation manuals and instructional texts.

Installers spent hours making successive adjustments to their set-ups, accepting the necessity of wasting time as a result of inaccurate inclinometers, suspecting inaccuracy of their dishes, and/or muttering and grumbling about the mysteries of satellite technology.

In 1985, Jim Roberts of Gourmet...Entertaining, rebelled at the excessive time required for alignment by the "conventional wisdom" and developed the ARC-SET—an accurate three-stage inclinometer. The concept was just to accurately copy what worked. This was accomplished by setting the ARC-SET's adjustments to duplicate the settings of a local "mother dish" already aligned to the Arc.

Initially, roughly one-in-five ARC-SET users had trouble with this simple approach. Investigation found that many existing dishes of that era had feeds which were off-center from the focal point of the dish, rendering them unsuitable for serving as a template. To allow ARC-SETs to be pre-set properly—in ignorance of Birkill's work—Jim's son Dan Roberts developed a trigonometry-based computer analysis of angles to the satellites. It was a high school scholarship project. This computer analysis calculated optimum set-up angles for satellite mounts based on minimizing the residual errors in satellite tracking—and listed those errors as proof of optimization. Dan's submission, which won only second prize in the local scholarship competition, subsequently was published in two satellite industry trade magazines in 1986.

Also in 1986—unaware of the work by Birkill or Roberts—Bob Bruns of Chaparral Communications developed a calculus-based analysis for minimum area between the Clarke Orbit circle and various eliptical sweeps resulting from modifying alignment angles within satellite mounts. The results were presented in Chaparral Technical Bulletins: Nos 88-18 "Polar Mount Chart" and 89-4 "Optimizing Dual Band Systems".

The values for axial slope and declination that were derived by Birkill, Roberts, and Brun match each other to within a few hundreths of a degree. This independent agreement gives confidence in the numeric values presented herein, although there is some disagreement as to the best method of applying them to satellite dish installations. (See Modified "Polar" Mount Alignment on page 118.)

Problems With Antenna Pointing

Determination of exactly which way the dish should be "looking" (i.e., receiving signal) can

be deceptive. If a dish which is intended to be symmetrically parabolic and center-fed has unintentional imperfections in the shaping of its reflective surface and/or inaccuracy in its feed centering, its "look" direction may not be straight out from its face slope.

Dishes intentionally designed as "off-set" or "spoon" reflectors have distinct advantages. Their feed is out of their field of reception. In the typical upright (catching the signals "over-hand") mounting they shed leaves and dirt easily. In the alternative on-their-back mounting (catching the signals "under-hand") their visibility and wind resistance is reduced, but they may require a drain hole to release rain. On their backs, they resemble a bird bath with the feed up, like a shower head.

A disadvantage, or at least an inconvenience, of off-set dishes is how to determine where they are "looking", which is germane when aligning them on a "Polar" mount. The axis orientation (True North-South and inclined by the proper amount more than the local Latitude) is independent of whether the dish is an off-set or a fully symmetrical parabolic reflector, but the "look" direction of the dish will vary with its design. Obviously they are receiving signal from a direction opposite to the feed and at an angle equal to the feed's eccentricity (i.e., the angle of incidence equals the angle of reflection). Some off-set mounts include a reference surface which is normal/perpendicular to the look-direction of the dish; without that, a temporary reference plate may be attached to the dish along a line of symmetry which includes the feed.

Fully symmetrical parabolic dishes (a.k.a. "Prime Focus", "Center Fed", or "Cassegrain") have the advantage of "looking" out in any direction normal/perpendicular to their face slope. Measurement of the face slope provides a convenient means to determine the elevation of the look angle of the dish. Many mounts have a frame, ring, or surface which is intended to be parallel to the dish's face. Such parallel surfaces at the rear of the antenna are more convenient to measure during alignment than walking around to measure the front face, but be careful that any surface/ring/frame used is parallel to the face slope.

Inefficiency will arise if the feed is even slightly off-center. An excellent analogy is to think about a searchlight with a straight beam of light going up into the night sky. It is easy to imagine what would happen to that beam if the light source were moved slightly in front of the searchlight's mirrored surface: the light beam would be cast off in the opposite direction and would become more spread (i.e., less efficiently focussed). A satellite dish works like a searchlight—in reverse! If the feed placement is off-center, in front of a dish intended to be fully symmetrical, that dish will "look" off in the opposite direction—and because of the beam spread, it will receive signals less efficiently than intended.

Correcting Unintentional Off-Center Feeds

In the interest of maximizing the signal capturing capability or "gain" of a dish, it is important to correct any mis-match of the feed's phase center to the dish's focal area for the highest frequency being received. Such a situation is often termed an off-center feed, even though the feed may be physically at the same distance from several points around the dish lip. It is easier, but robs the dish of some available gain, to cover up the situation by making a compensating adjustment in the declination.

Alignment methods which prescribe careful setting of the declination, and then adjusting the axial inclination to maximize the highest satellite's signal are vulnerable to covering up off-center feed situations. The Axis orientation to True North/South and to the local latitude's AXIS inclination should be exact, with any "look" adjustment made above it—as with spoon dishes.

It is possible to re-capture the available focus gain of a misshapen dish (an apparent off-center feed situation) by using the two known dish slopes (EXTREME and ZENITH) and forcing the feed into the strongest gain/reception position in front of the dish as describer in section 5. This work is not easy, especially if access to the front of the dish face is inconvenient, but it will maximize the system's perfor-

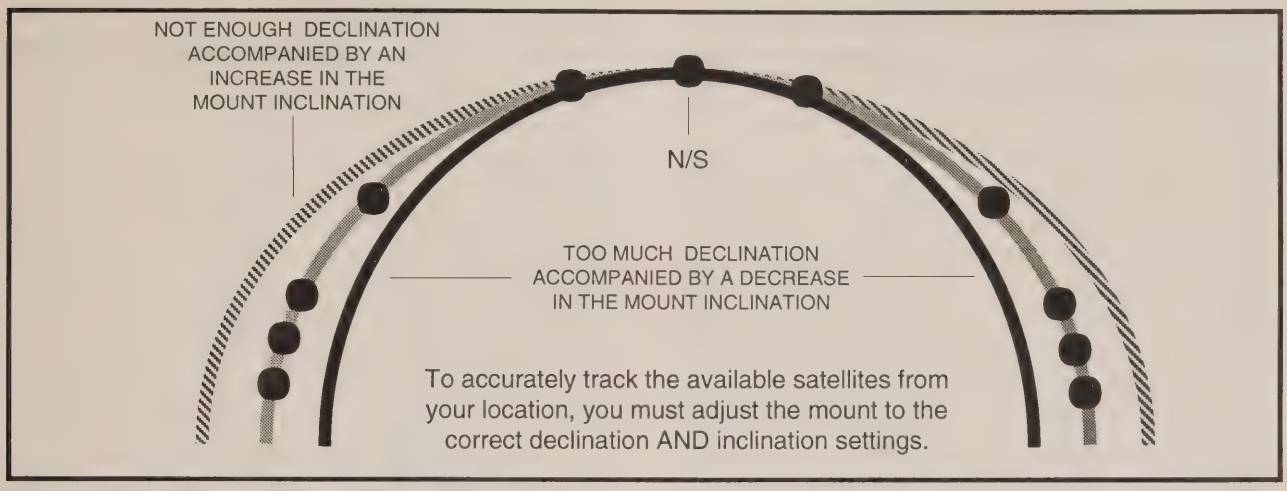

NOT ENOUGH DECLINATION
ACCOMPANIED BY AN
INCREASE IN THE
MOUNT INCLINATION
N/S
TOO MUCH DECLINATION
ACCOMPANIED BY A DECREASE
IN THE MOUNT INCLINATION
To accurately track the available satellites from
your location, you must adjust the mount to the
correct declination AND inclination settings.

Fig.9-6. Effects of compensating for incorrect declination by increasing or decreasing inclination.

mance better than anything short of rebuilding or replacing the dish.

Modified "Polar" Mount Alignment

There is agreement on the end goal of aligning satellite dish mounts so that the dish is looking out at an angle which is appropriately off-set for the local Latitude; from an axis suitably inclined for that Latitude; and oriented True North-South.

The Mount's "Polar" Axis is inclined, relative to the local horizontal, by Fig. 9-7's MOUNT AXIS angular value for the site's Latitude, and is oriented true North/South. The satellite dish is "off-set" from the MOUNT AXIS or tips additionally toward the equator by the Fig. 9-7's DECLINATION angular value for the site's Latitude.

Symmetrical parabolic dishes with centered feeds receive signals ("look") at right angle to their face. Face slope thus offers a convenient tangible measurement for the complement of (ninety degrees minus) the "look" direction. At their highest "look" position, these dishes are tipped toward the equator so that their face slope is inclined to the ZENITH angular value for the site's Latitude presented in Fig. 9-7.

Setting up a satellite dish on a Modified "Polar" Mount can be reduced to a relatively simple three-dimensional problem. Gourmet...Entertaining's patent-pending method, for which the ARC-SET tool was designed, solves the "Polar" Mount alignment problem with three precise angular measurements of inclinations and then turning the Mount in azimuth to peak reception from one satellite. This method utilizes the tabulated values of AXIS and ZENITH presented in Fig. 9-7 and the Dish Slope values presented in Fig. 9-3. This method avoids the need for a compass or a plumb dish support. The mount's foundation post must be solid/stable—but may be out of plumb toward any direction to any amount (limited only by the amount of mechanical adjustment available in the mount design). For those without the ARC-SET tool, the Gourmet...Entertaining method also can be used with any accurate inclinometer as follows:

1). Precisely set the mount AXIS inclination for the site's latitude value in Fig. 9-7. Mount axis is the slope of the Mount's axial line about which rotation occurs to change satellites. The "Polar" axis inclination will be the same for the latitude, no matter what kind/style of antenna or feedhorn may be mounted over it. The AXIS inclination, once properly set, should not be altered, unless re-setting to the correct value is necessary due to later turning on a non-plumb foundation.

2). Precisely set the declination, off-setting the "look" direction (of reception), from perpendicular to the Axis. With a properly constructed center-fed dish, this can be accomplished by actuating the dish up to its highest "look" position (ZENITH). At this position the declina-

LAT	MOUNT AXIS	DECLINATION	ZENITH	LAT	MOUNT AXIS	DECLINATION	ZENITH
0	0	0	0	41	41.71	5.67	47.38
1	1.03	0.15	1.18	42	42.72	5.78	48.50
2	2.05	0.31	2.36	43	43.72	5.89	49.61
3	3.08	0.45	3.53	44	44.72	6.00	50.72
4	4.10	0.61	4.71	45	45.71	6.11	51.82
5	5.13	0.76	5.89	46	46.71	6.22	52.92
6	6.16	0.90	7.06	47	47.70	6.32	54.02
7	7.18	1.06	8.24	48	48.70	6.42	55.12
8	8.21	1.21	9.42	49	49.70	6.52	56.21
9	9.23	1.37	10.59	50	50.69	6.61	57.31
10	10.26	1.51	11.77	51	51.69	6.70	58.39
11	11.28	1.66	12.94	52	52.68	6.80	59.48
12	12.31	1.80	14.11	53	53.67	6.89	60.56
13	13.33	1.95	15.28	54	54.67	6.97	61.64
14	14.35	2.10	16.45	55	55.66	7.06	62.74
15	15.37	2.25	17.62	56	56.65	7.14	63.79
16	16.40	2.39	18.79	57	57.64	7.22	64.86
17	17.42	2.54	19.96	58	58.63	7.30	65.93
18	18.44	2.68	21.12	59	59.61	7.38	67.00
19	19.46	2.82	22.28	60	60.59	7.46	68.06
20	20.48	2.97	23.45	61	61.58	7.53	69.12
21	21.50	3.11	24.61	62	62.57	7.60	70.17
22	22.52	3.25	25.77	63	63.55	7.67	71.23
23	23.54	3.38	26.92	64	64.54	7.74	72.28
24	24.55	3.53	28.08	65	65.52	7.80	73.32
25	25.57	3.66	29.23	66	66.50	7.86	74.37
26	26.58	3.80	30.38	67	67.49	7.92	75.41
27	27.59	3.94	31.53	68	68.74	7.98	76.45
28	28.61	4.07	32.68	69	69.45	8.03	77.48
29	29.62	4.20	33.82	70	70.43	8.09	78.52
30	30.63	4.33	34.96	71	71.41	8.14	79.55
31	31.64	4.47	36.11	72	72.39	8.18	80.57
32	32.66	4.59	37.25	73	73.37	8.23	81.60
33	33.67	4.71	38.38	74	74.35	8.27	82.62
34	34.67	4.85	39.52	75	75.33	8.31	83.64
35	35.68	4.97	40.65	76	76.31	8.34	84.65
36	36.69	5.09	41.78	77	77.27	8.38	85.67
37	37.69	5.21	42.90	78	78.27	8.41	86.68
38	38.70	5.33	44.03	79	79.25	8.43	87.68
39	39.70	5.45	45.15	80	80.22	8.47	88.69
40	40.71	5.56	46.27	81	81.20	8.49	89.69

Fig. 9-7. Axis, Zenith & Declination Values by Latitude. The values in this table are rounded to the nearest one hundredth of a degree, which is realistic in terms of practical field measurement, as well as stationkeeping accuracy of mechanical mounting mechanisms. The geometry of Polar Mounts allows the elliptical sweep of reception/look direction to acquire each above-the-horizon geostationary satellite in the Clarke Orbit to within a few ten thousandths of a degree.

tion angle is in the vertical plane of the AXIS inclination. Use the declination adjustment to bring the dish slope to the ZENITH value for the site's latitude value provided in Fig. 9-7.

3). After setting the AXIS and Declination, set the true North/South orientation of the Polar Axis by actuating the dish over toward the side which will have the lowest receivable satellite. Actuate the dish until its steepest slope (look direction) is precisely correct for reception of that satellite (the EXTREME setting of the ARC-SET, or the dish slope derived from Fig. 9-1) and then turn the dish/mount in azimuth to peak reception from that satellite. This will bring you to the True North/South orientation of the Axis. This uses the signal from the satellite which is most unforgiving of inaccuracy in the Axial Azimuth to insure that True North/South has been found.

4). To confirm that the dish is fully tracking the satellite arc, actuate it to the satellite at the opposite end of the visible arc. After peaking reception of this satellite with the actuation, use the most convenient means/mechanism available to slightly shift the "look direction" of the dish away from the path of actuation, without loosening/changing the azimuth setting achieved in 3). On a large rigid dish mount, this may be done by slightly altering the Declination adjustment. On smaller, more flexible dish/mounts, this may be done by gently lifting the point of the dish lip which is closest to the ground and then gently pressing down on that lowest point of the dish lip, and then gently tugging one side (and then the other) to pull the "lookdirection" of the dish slightly East-West. The satellite's signal should drop off with both directions of Declination alteration (or tugging, lifting, lowering of the dish lip's lowest point) to confirm that you have tracked the arc. Gently pushing or lifting on the lip of the dish causes a flexible dish to slightly change/lose its parabolic shape. That will cause the satellite signal strength to drop off. If the signal improves with either Declination alteration—or tugging, lifting or pressing down on the dish lip (overcoming the signal drop off due to shape loss—this indicates that one of the following errors is taking place: a mismeasurement of one of the elevations (some convenient surface used for taking readings is not parallel to the dish face's slope) or the feed is off-center from the dish's center of concentration or "focal point", which in reality is a small region or area of concentration which more correctly can be called a "focal cloud".

5). To check/correct such errors, re-check that the slope of the mount's axial line is at the value set in 1). Then actuate the dish back up to its highest "look direction" and re-check that the dish face's slope is at the ZENITH value set in 2). Bridging either side of the dish face (10 o'clock to 8 o'clock, or 2 o'clock to 4 o'clock) should suffice—you do not need to bridge the full diameter (12 o'clock to 6 o'clock). Then actuate the dish to peak the signal from the satellite closest to true North/South. Check to see if moving the feed along the line from highest, to lowest, dish lip (or altering Declination) increases the satellite's signal strength. Moving the feed is preferable because that puts the feed more into the "as-built" dish's "focal cloud", but it is less convenient than altering declination. In either case the inclination of the mount's axial line should not be changed from the value set in 1). Then actuate the dish back to the lowest visible satellite and re-check that the dish face's slope is the value set in 3). Again bridging either side of the dish face is appropriate to be sure of the correct inclination. With the dish face's slope correct, lossen the foundation attachment and re-check that the azimuth orientation is producing maximum satellite signal. Re-tighten the foundation attachment at maximum signal and move the feed, in front of the dish, along what is now the line from highest (to lowest) points of the dish lip to find the position of maximum signal.

All this re-checking and re-adjustment should rarely be necessary if you are careful in your choice of reference surfaces and fortunate enough to be working on well-shaped dishes with properly matched feeds.

Non Plumb Foundations

For proper tracking, the mount axis must be set correctly and oriented true North/South. This axis can be supported either by a single

pole or by a different configuration such as a tripod mount. If the dish foundation is not plumb, the slope of the dish will change as turning for the azimuth peaking in 3). is attempted. This need not be a major problem. Just actuate the dish up (or down) as necessary to preserve the proper slope. Preserving the slope (and thus the "look" elevation) of the dish will allow you to find the lower satellite as you turn the dish in Azimuth.

After you have acquired the satellite signal from the lowest satellite and thus are close to a true North/South orientation for the mount, you must re-set the AXIS inclination (which will have changed during turning on the non-plumb foundation) back to the original inclination. If a major re-adjustment is required, you will probably note deterioration of your reception and some change in the dish slope. Just actuate the dish back to the EXTREME slope and make a small further turning adjustment to recover the signal peaking. The Mount's correct three dimensional orientation is achieved when its Axis is precisely inclined, the "look" direction is precisely offset from the Axis, and the lowest satellite's signal has been peaked by using the correct amount of actuation and rotation of Azimuth to locate true North/South.

For dual-band satellite receiving systems, it is functional to peak reception of the higher band (shorter wavelength) signals and rely on the lower tolerances involved in receiving the more forgiving lower frequencies. With some poorly shaped dishes, the "focal clouds" of different frequencies are physically separated to such an extent that installation of a new dish will be necessary to achieve dual-band reception from a single antenna.

Elementary AZ/EL Computer Programs

The following elementary computer programs calculate the inclinations of interest for all satellites which can be received from any site location.

ELEMENTARY COMPUTER BASIC (with Radian conversion in Trigonometic functions)

```
10  E=3959
20  C=26200
30  INPUT "SITE LATITUDE":A
40  INPUT "SITE LONGITUDE":LS
50  INPUT "SATELLITE LONGITUDE":LB
60  S=LB-LS
70  D=SQR((C*COS(S)-
    E*COS(A))2+(C*SIN(S))2+(E*SIN(A))2)
80  AZ=ATN(TAN(S)/SIN(A))+180
90  EL=ACN(((D*D)+(E*E)-(C*C))/(2*D*E))-90
100 SK = ATN(SIN(S)/TAN(A))
110 PRINT:AZ:EL:SK
```

TEXAS INSTRUMENT BASIC
(T.I. 99/4 Computer)

```
100 E=3959
110 C=26200
120 RADIANS=0.0174533
130 INPUT "SITE LATITUDE?":A
140 A=A*RADIANS
150 INPUT "SITE LONGITUDE ?":LS
160 INPUT "SATELLITE LONGITUDE ?":LB
170 S=(LB-LS)*RADIANS
180 D=SQR((C*COS(S)-
    E*COS(A))2+(C*SIN(S))2+(E*SIN(A))2)
190 AZ=ATN(TAN(S)/SIN(A))
200 AZ=(AZ/RADIANS)+180
210 VL=((D*D) + (E*E)-(C*C))/(2*D*E)
220 EL=1.5708-ATN((VL)/SQR(1-(VL*VL)))
230 EL=(EL/RADIANS)-90
240 SK=ATN(SIN(S)/TAN(A))
250 SK=(SK/RADIANS)
260 PRINT: AZ:EL:SK
270 END
```

NOTE: Lines 120 and 140 are accommodations to this machine needing specific angular conversion into, and out of, Radians—as are the complexity of 170, 200, 230 & 250. Line 220 is an accommodation to this machine not knowing ArcCos. If it did: 220 EL=ACN(VL).

Chapter 10

Tracking Inclined Orbit Satellites

Man-made satellites can be placed along many different paths—or orbits—as they revolve about the Earth. The plane of these orbits can be equatorial, polar, or inclined. A polar orbit has a plane that is more or less parallel to the Earth's polar axis, while the plane of the geostationary orbit is equatorial in nature, lying parallel to the Earth's equator. Orbits that are offset in degrees from the Earth's equatorial plane are called "inclined orbits".

The communications satellites in geostationary orbit are located above the equator and revolve around the earth at the same rate the Earth rotates on its axis. To an observer or satellite antenna on the ground these satellites appear to be stationary. However, geostationary satellites are constantly being subjected to forces such as the gravitational attraction of the Sun and Moon, the radiation force from sunlight, and the Earth's gravitational field, all of which create a tendency for any "stationary" satellite to drift away from its assigned "subsatellite point" over the Earth's equator.

The satellite's momentum and the Earth's gravitational field act to keep the satellites in geosynchronous orbit—a prograde orbit having a period equal to that of the Earth's rotation but not necessarily geostationary. The gravitational attraction of the Moon and the Sun primarily affect the orbit in a North-South direction while the radiation force of sunlight and the "asymmetry" in the Earth's gravitational field primarily influence the orbit in an East-West direction.

Under normal stationkeeping procedures, most geostationary communications satellites are allowed to wander ±0.1 degrees in the North/South direction and ±0.05 degrees in the

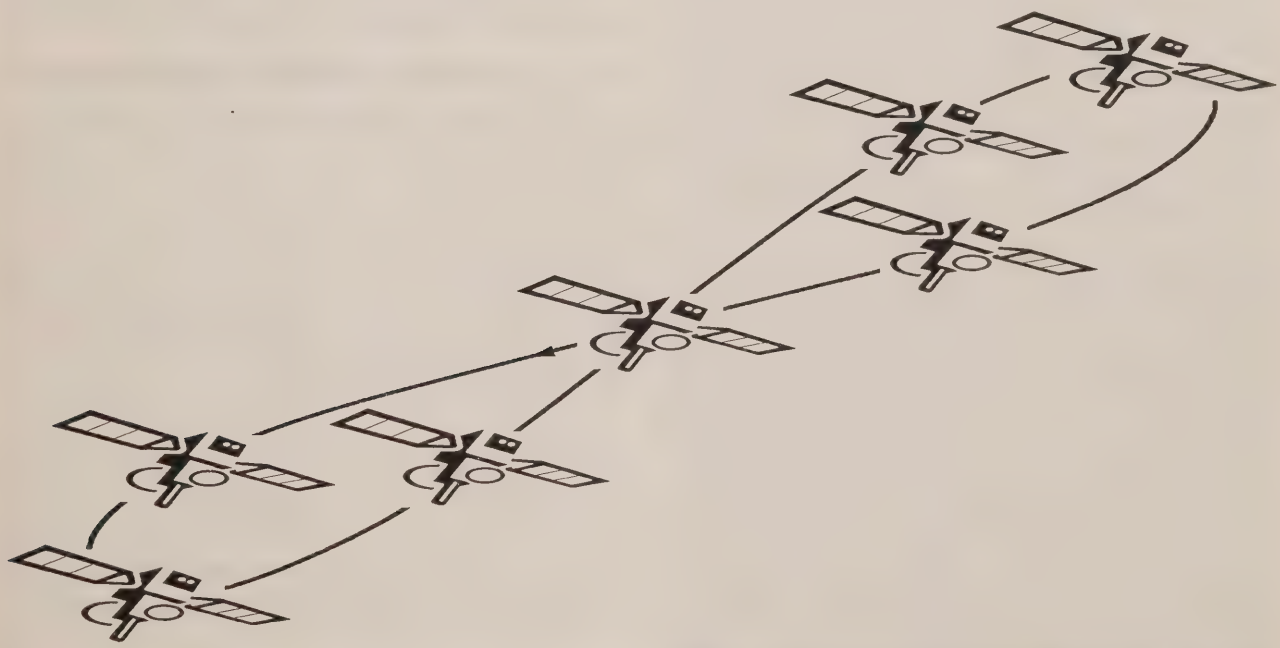


Fig. 10-1. A geosynchronous orbit is a prograde orbit having a period equal to that of the Earth's rotation (i.e., 24 hours) but not necessarily geostationary.

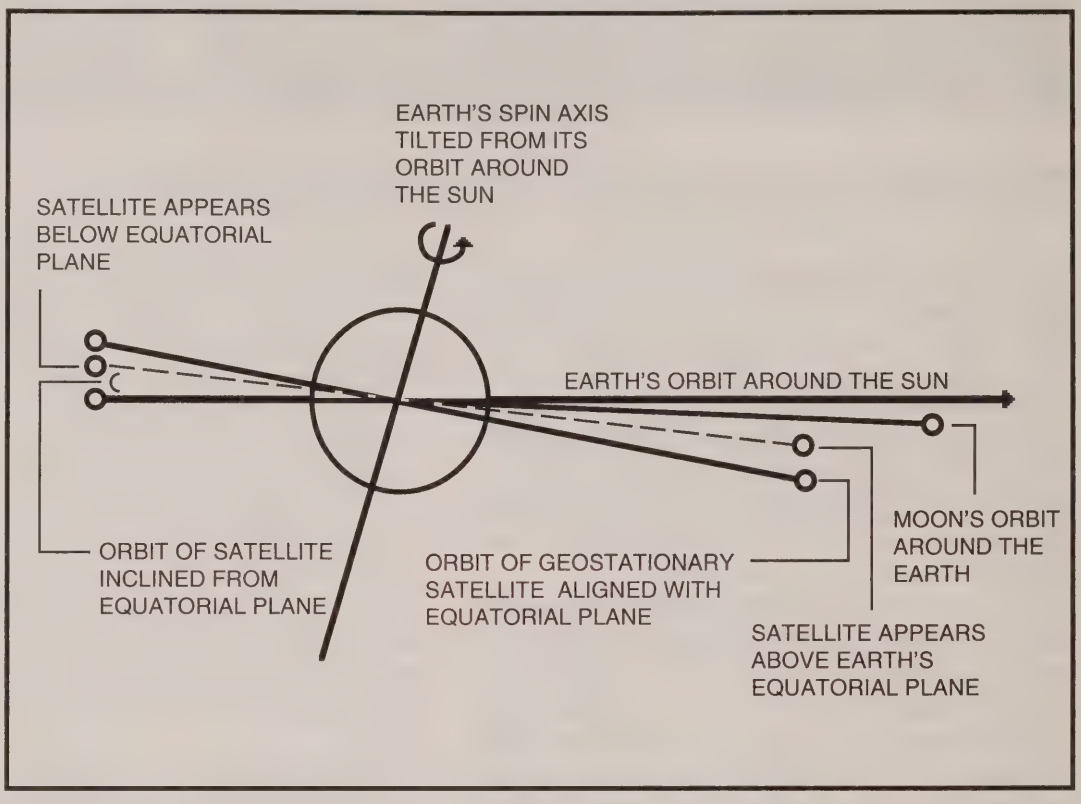


Fig. 10-2. When viewed from the side, it can be seen that for the entire day the Sun and Moon pull on the satellite in the direction to align it with their orbits. With no North/South stationkeeping, the satellite's orbit is continously pulled away from its desired orientation and becomes inclined with respect to the Earth's equatorial plane. (Concept courtesy of Sea Tel).

East/West direction from their assigned longitudinal positions over the Earth's equator. Stationkeeping fuel onboard the satellite is periodically used to keep the satellite confined to this celestial "box". These corrections are performed by firing thrusters, pushing the satellite back toward its assigned position. The maneuverability of the satellite, and thus its useful lifetime, is limited to the amount of stationkeeping fuel onboard the satellite when it reaches its assigned position and how well the expenditure of stationkeeping fuel is managed over the lifetime of the spacecraft.

If the satellite operator were to cease East-West stationkeeping, the satellite would begin to drift away from one of two natural "peaks" of orbital equilibrium located at approximately 11 degrees West Longitude and 162 degrees East Longitude and move toward the nearest of two "valleys" located at about 105 degrees West Longitude and 75 degrees East Longitude. In between each peak and valley in the geostationary arc are areas of maximum East or West influence. Satellites located near the areas of maximum influence therefore have to counteract greater forces than those located at the "valleys" of the arc.

If an operational satellite were allowed to drift away from its assigned orbital position towards

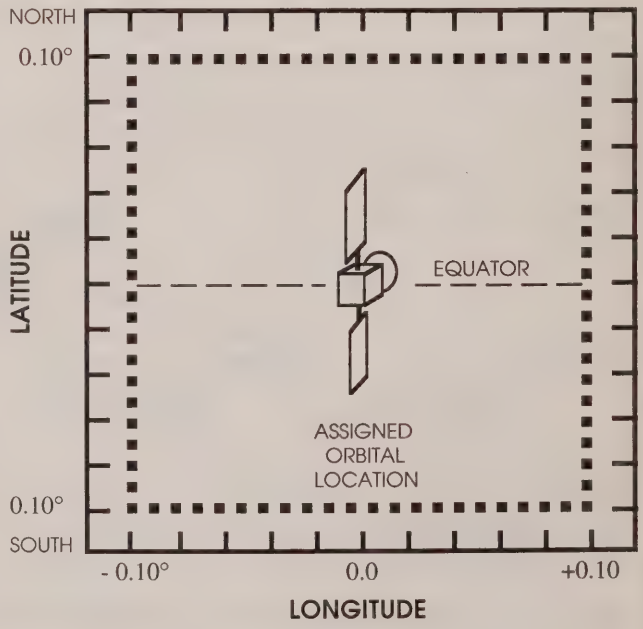


Fig. 10-3. Geostationary Stationkeeping "Box".

one of these valleys, it could cause interference to satellites positioned at other orbital locations within the geostationary arc as the drifting spacecraft passed them by. Eventually the satellite would go beyond the Earth's horizon as seen from the location of the controlling uplink site. This particular situation happened twice in 1992, when both the Arabsat 1A and 1B satellites unexpectedly ran out of East-West stationkeeping fuel and drifted Eastward toward the valley at 75 degrees East Longitude. The Arabsat consortium continued to operate the satellites as they drfited Eastward until they reached the vicinity of the Indian Ocean INTELSAT satellite cluster which ranges from 57 to 66 degrees East Longitude. As each Arabsat satellite approached the Indian Ocean INTELSAT cluster, their communications payloads were shut down to prevent interference to the INTELSAT spacecraft.

Fortunately it takes relatively little fuel to correct for East-West drift of the satellite compared to the larger amount of fuel needed to correct the North-South drift. By keeping the satellite's Longitude controlled but letting the satellite drift in Latitude (i.e., the North-South direction), the lifetime of the satellite can be greatly extended.

Understanding Orbital Inclination

It is in the North-South direction—perpendicular to the direction of orbital motion about the Earth's equator—that the Sun and Moon exert their most influence. When a satellite begins to drift in the North-South direction the effect is to decircularize the orbit, forming an ellipse with an apparent daily or "diurnal" East-West motion about the assigned sub-satellite point above the equator. As luck would have it, however, the circular orbit induces a certain amount of rigidity to the elliptical motion of the spacecraft which counteracts the East-West motion to a great extent, thereby holding the ellipticity to a low level throughout the lifetime of the spacecraft.

Given an initial movement to the North of the subsatellite point, the spacecraft must continue to orbit the Earth's center, so that twelve hours later, the satellite will have crossed the equator heading in the South direction. The satellite moves at the fastest speed at the twice-daily equatorial crossing and slowest at the North and South apexes of the inclined orbit. The period of the North-South motion is nearly 24 hours in what is known as "sidereal time" — the equivalent of 23 hours, 56 minutes, and 4 seconds in mean solar time, allowing for the Earth's progress around the Sun during the course of one rotation.

Stationkeeping Fuel Expenditures

A good explaination of fuel consumption is detailed in Comsat's U.S. patent number 4,776,540 which states: *".....a conventional satellite such as Comstar (Trademark), uses an average of 37 pounds of fuel for stationkeeping during each year of the latter part of its design life. Of the 37 pounds of fuel consumed in a year, approximately 34 pounds are used for north/south correction, while only 2 pounds are used for east/west correction and 1 pound for attitude control. Since such a conventional satellite is provided with approximately 340 pounds of fuel and uses more of that fuel in the earlier part of its design life, it is expected to run out of fuel in just over 7 years."*

If North/South stationkeeping is eliminated, the fuel can then be used for East/West stationkeeping. A general rule-of-thumb here is that for every month of North/South stationkeeping fuel which is diverted to East/West stationkeeping the useful life of the satellite in an inclined orbit can be prolonged by one year.

Spin-stabilized spacecraft carry two fuel tanks with a valve between them. When the spacecraft approaches the final 12 to 18 months of its normal mission life, the valve is opened and a series of maneuvers are initiated to adjust the fuel levels in the two tanks so that they are balanced, or equal in content. The valve is then closed and the fuel is gradually consumed from only one of the tanks. Once this tank's contents is depleted, the engineers can then calculate the amount of fuel still remaining in the other tank and consequently determine just how many months they can continue to perform normal geostationary operations or by how

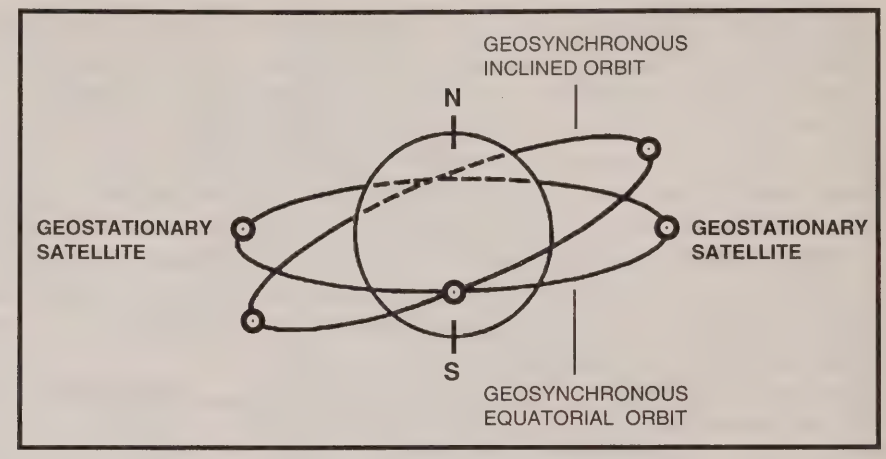


Fig. 10-4. Geosynchronous equatorial versus geosynchronous inclined orbits.

many years the useful life of the satellite can be extended by discontinuing North/South stationkeeping.

Other Limitations Governing Inclined Orbit Operations

Beyond the fuel considerations, there are other potential limiting factors governing use of the inclined orbit mode by a communications satellite. One question that readily comes to mind is just how much of an inclination can be used without causing interference to other satellite systems or to terrestrial communications networks which share frequency spectrum with communications satellites.

In 1992, the World Administrative Radio Conference (WARC-92) met to determine world telecommunications policy for the next ten years. Operating under the auspices of the International Telecommunication Union—a principal agency of the United Nations—WARC decisions act as treaties among nations.

WARC-92 examined the maximum allowable inclination angle of satellite networks using slightly inclined geosynchronous satellite orbits. While WARC-92 decided not to adopt any specific values of maximum inclination, the Conference noted that from a technical standpoint, in frequency bands which are not shared with terrestrial systems, geostationary satellites can operate until reaching a natural inclination limit of 15 degrees without causing significant interference to other satellite networks. However, in frequency bands shared with terrestrial systems, WARC-92 noted that the natural limit may not be acceptable and that the maximum inclination angle has yet to be clarified. In practice, satellite operators have, for the most part, elected to cease inclined orbit transmissions before a communications satellite exceeds an inclination value of ±6.0 degrees.

The Mechanics of Inclined Orbit Operations

The orbital inclination of a satellite is defined as the angle in degrees of the plane of the satellite's orbit relative to the Earth's equatorial plane. (Polar orbiting satellites have inclinations near 90 degrees taking them over the poles.) Typically the inclination of geostationary satellites is kept to less than ±0.1 degree. If North-South stationkeeping is stopped the inclination angle of the satellite will gradually increase. The annual change in inclination varies from year to year, averaging about 0.8 degrees per year during the early 1990s. The effect changes because the angle between the plane of the Moon's orbit and the equatorial plane changes from year to year.

A large percentage of today's communications satellites are currently operating in the inclined orbit mode. The major drawback to this mode of operation is that since the satellite appears to be moving as viewed from the ground, the antennas on the ground must now track the satellite's movement.

As the inclined-orbit satellite circumnavigates the Earth it exhibits a daily North-South oscillation. Even though the satellite is travel-

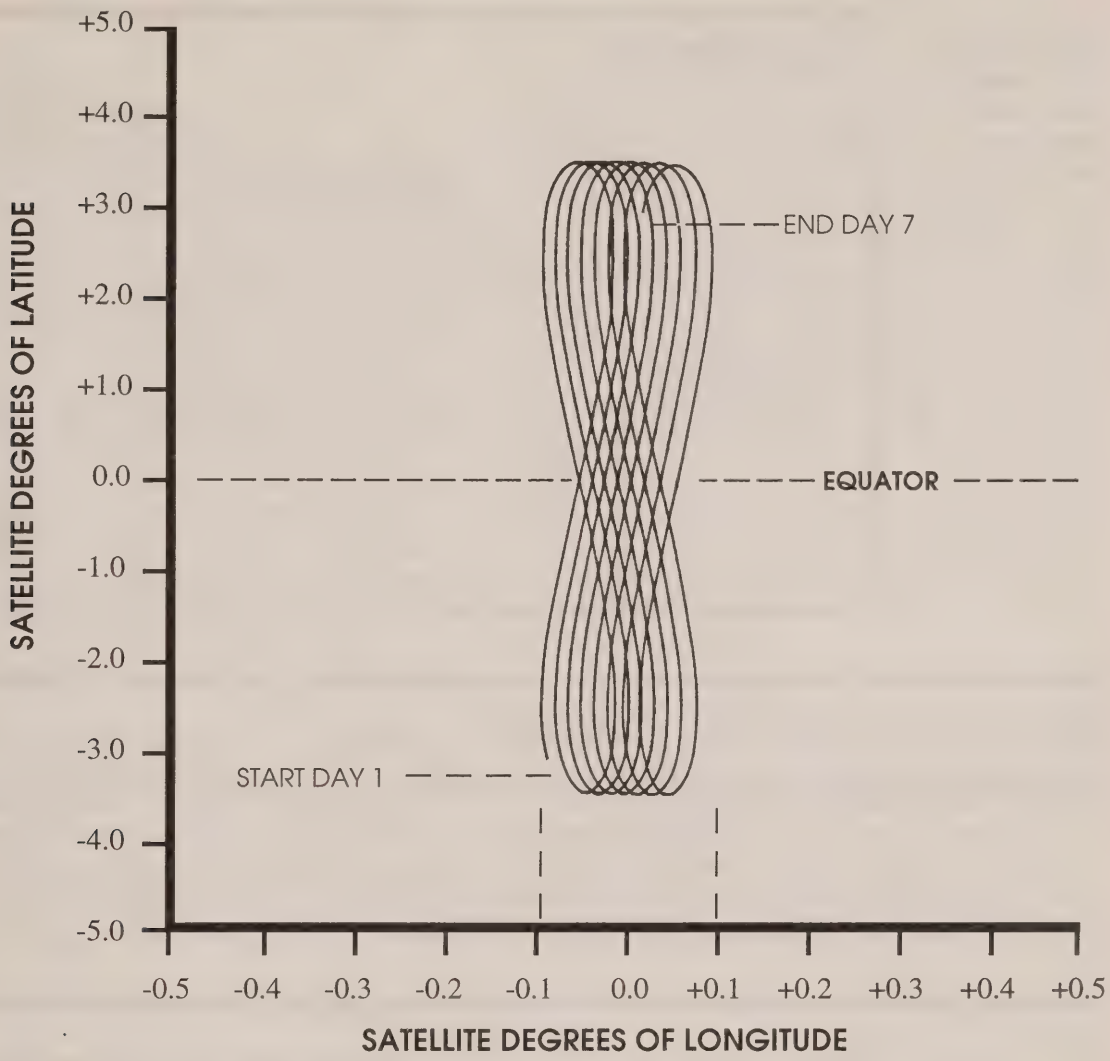


Fig. 10-5. Satellite Motion in 3.5° Inclined Orbit Over a Seven-Day Period.The above plot of a 3.5° inclined orbit satellite over a seven day period shows the degree of East/West motion which will occur. At the end of the 7-day period, the satellite operators will initiate stationkeeping commands that will reverse the direction of the East/West drift so that the satellite remains within its ±0.1°longitudinal "box". Whenever the inclined orbit exceeds 4 degrees of North/South movement, the width of the figure-eight motion will begin to exceed ±0.1 degrees.

ing at the rotational speed of the Earth, to an observer on the ground its position will trace a slim "figure 8" pattern in the sky over the course of each 24 hour period. At small inclinations, the pattern of satellite motion is actually a very narrow elliptical shape, appearing for all intents and purposes as a straight line. This pattern becomes more of a figure 8 as the orbital inclination of the satellite increases.

The actual shape of the figure-eight curve depends upon the value of the inclination angle, "i". In a pioneering article which first appeared in *CATJ* magazine during the early 1980s, Stephen J. Birkill presented the following description of the inclined orbit: "At the left side of this chart is the track of the subsatellite point for an inclination of 30 degrees. The numbers along the curve are hours from ascending node (North-bound equator crossing). By contrast, the short line at the right of the diagram is the

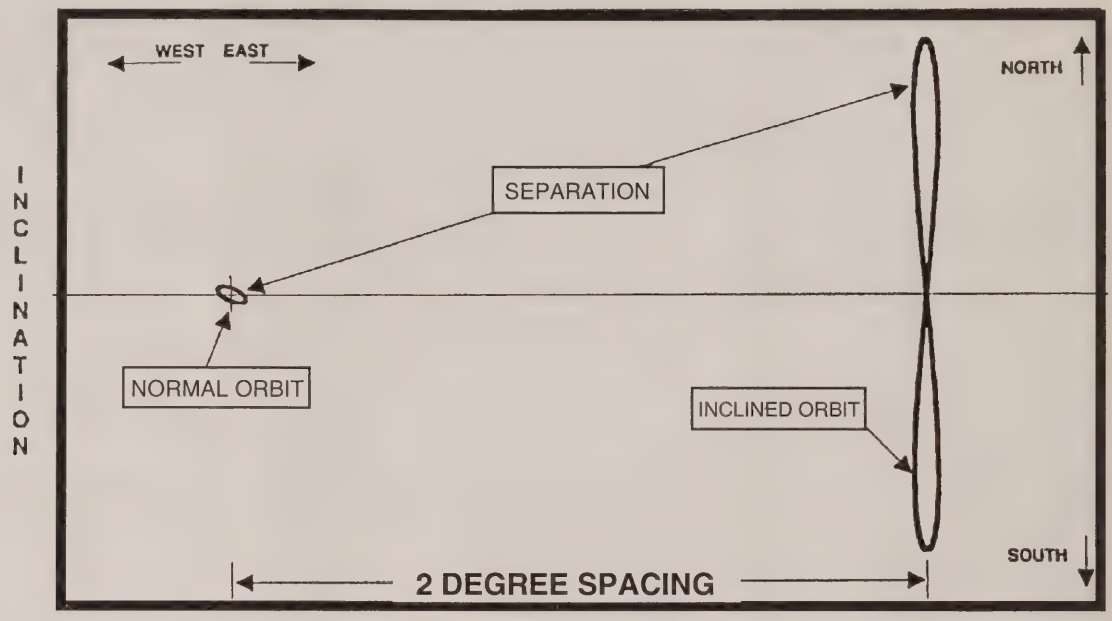


Fig. 10-6. Orbit trajectories for two geosynchronous satellites.

ground track for three-degree orbital inclination, drawn to the same scale. To make it clearer, the 3 degree orbital inclination has been scaled up by a factor of ten and redrawn at center. Its width in the East-West direction is seen to be a small fraction of its North-South extent. In fact the East-West component of motion is less than ±0.04 degrees in Longitude, for i - 3°. Considering that even a 6-meter antenna has a half-power beamwidth (at 4 GHz) of 0.9 degrees, and that most domestic birds have a stationkeeping tolerance of ±0.1 degrees or better, it is clear that we can neglect the "width" of the figure eight curve for all practical

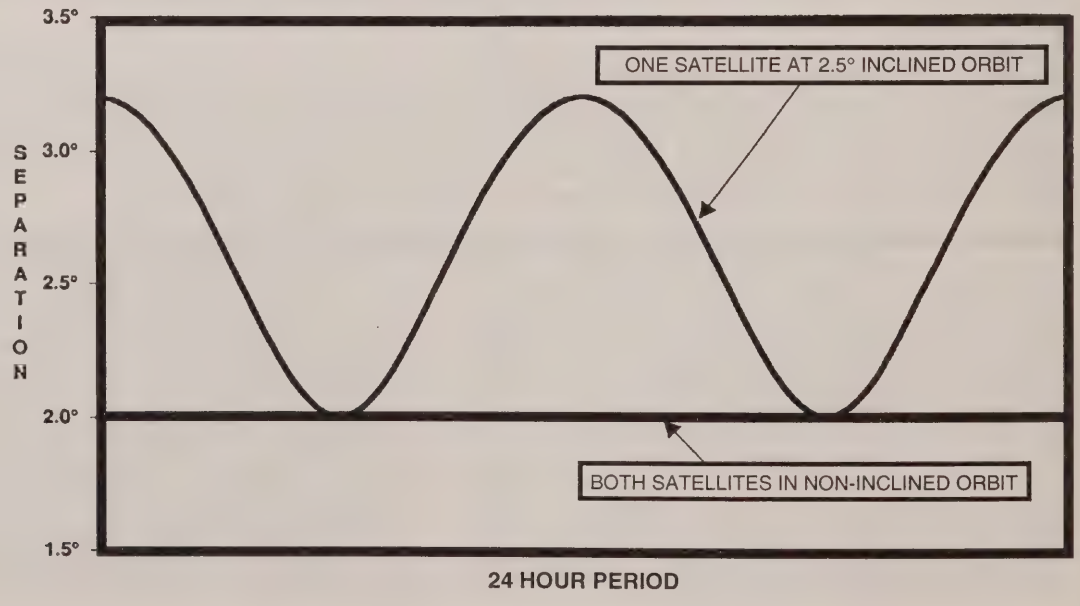


Fig.10-7. Mean separation between two adjacent 2 degree spaced satellites.

purposes for small values of orbital inclination."

Inclined Orbit Satellites and the Comsat Maneuver

Geostationary satellites occupy relatively fixed points in the sky when viewed from the Earth and their footprints remain continuously directed at their respective coverage areas on the ground. The antenna pattern or "footprint "generated by inclined orbit satellites, however, will shift its center point from the desired coverage area to locations to the North and South. Even if all associated ground stations are able to track the drift of the satellite, the shift in the satellite's footprint causes the signal's effective isotropic radiated power or "EIRP" to fluctuate, often in a dramatic fashion. At certain times of the day, some ground stations may even lose all communications with the satellite due to the signal levels falling far below minimally acceptable values.

To counteract these effects, a proprietary orbital technique called the "Comsat Maneuver" is being used by various satellite operators—including Comsat, Hughes, and INTELSAT—to prevent their older spacecraft operating in an inclined orbit mode from dramatically shifting the directivity of their beams. The Comsat Maneuver consists of subtle, but precise, changes in the physical orientation or "attitude" of the satellite that are commanded by the controlling earth station. These periodic changes in orientation ensure that the antenna pattern remains centered over the desired coverage area. The satellite's North and South movements still occur, but now each network's uplink and downlink antennas can maintain relatively constant signal levels by tracking the movement of the inclined orbit satellite. Motorized antenna systems are used to alter the declination or inclination of all associated earth stations in the system.

Even when the Comsat Maneuver is used, however, there will be some fluctuation in EIRP down on the ground. The amount of variation is

Fig. 10-8. Yearly Orbital Inclination Fluctuations Caused by Solar and Lunar Effects.

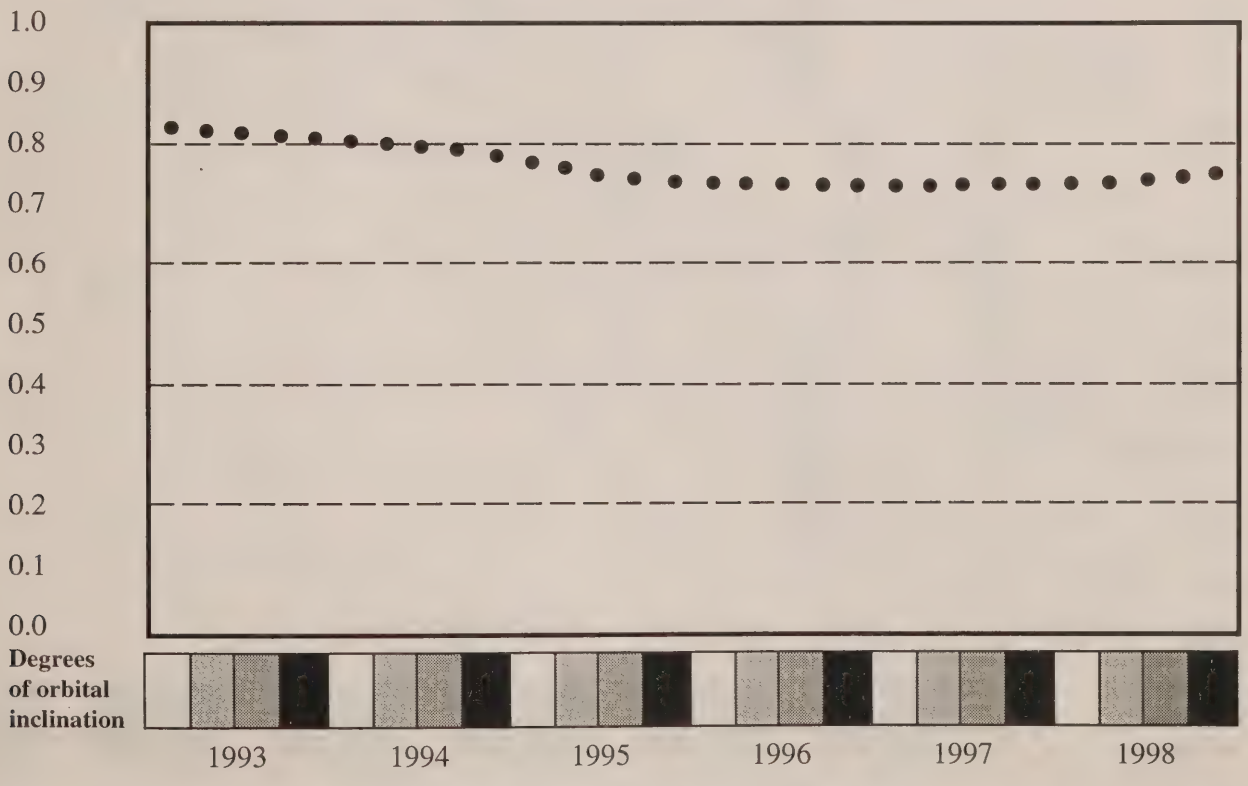
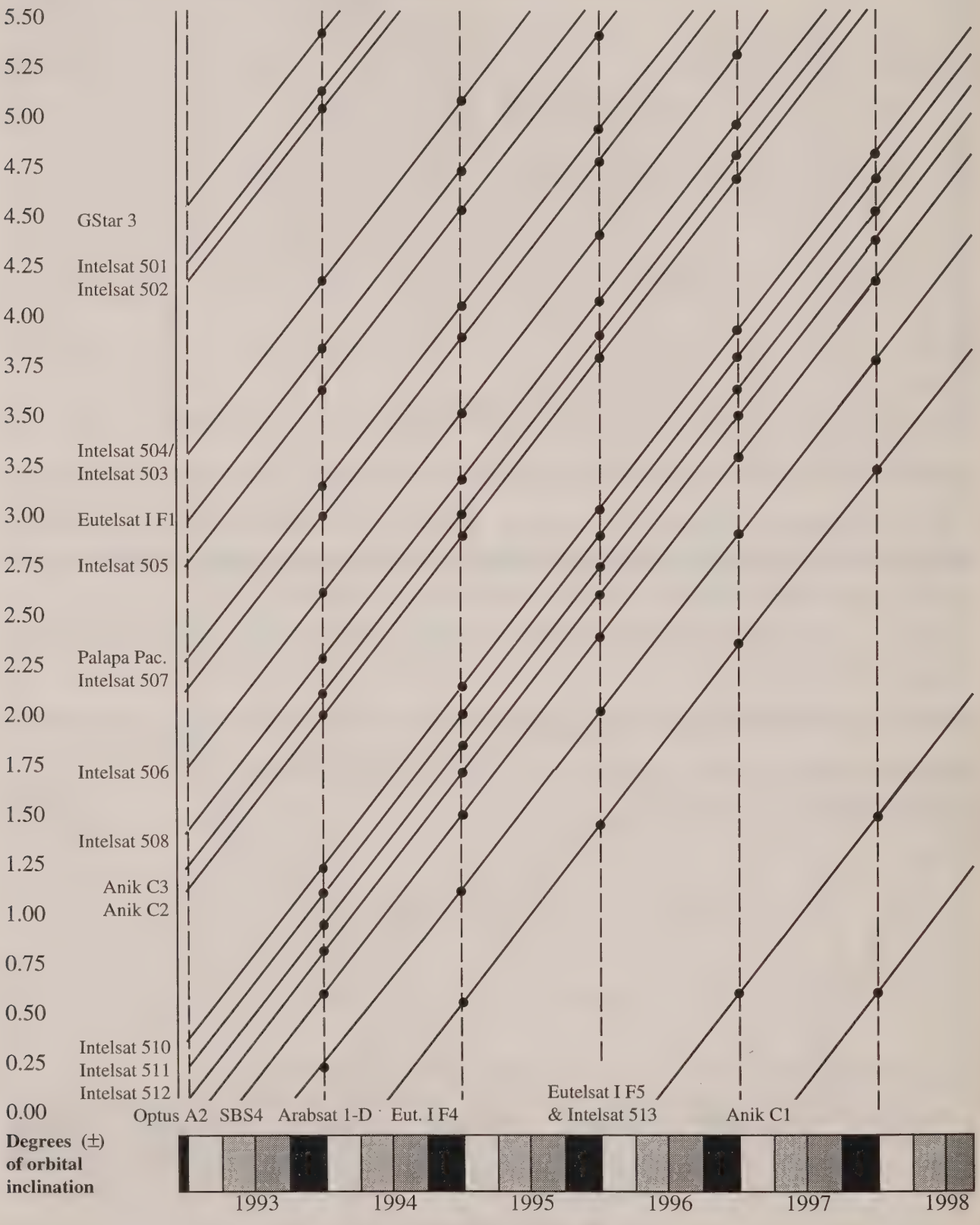
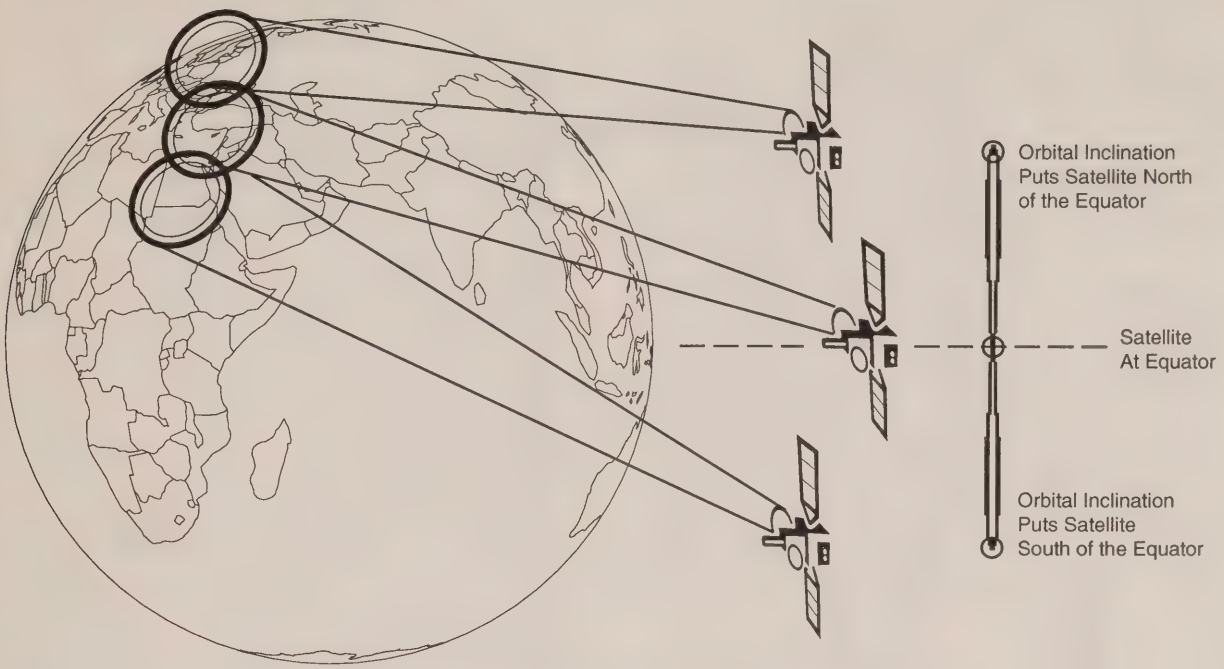
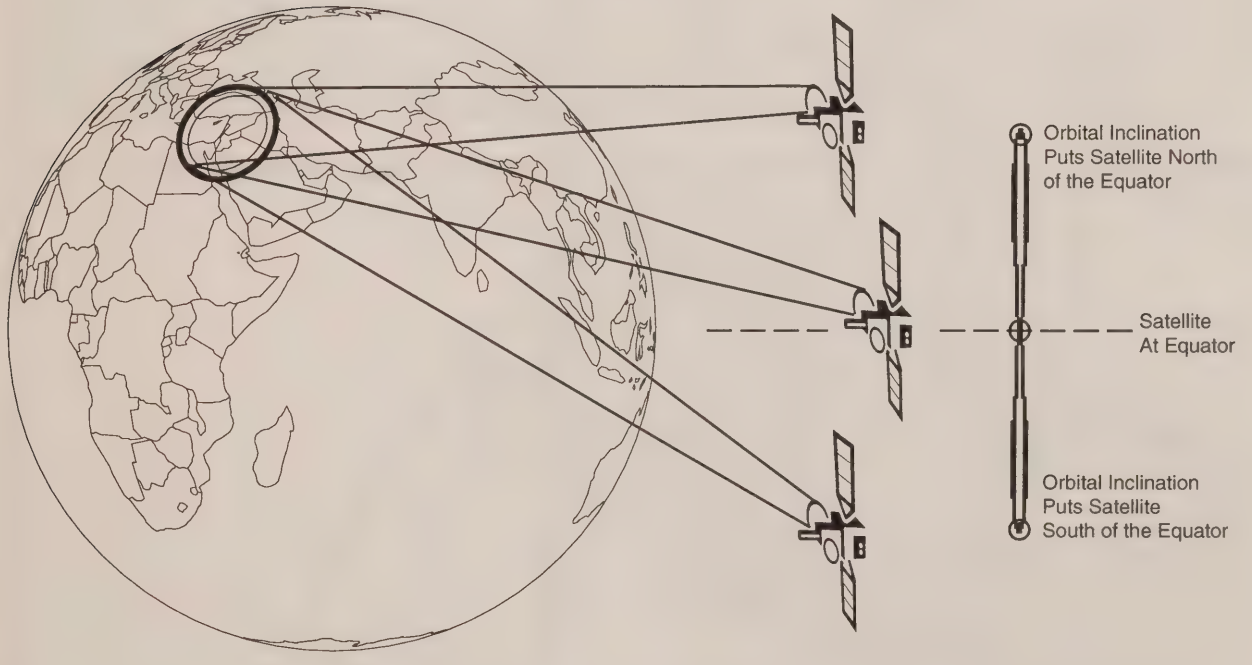


Fig. 10-9. Estimated Orbital Inclinations for Existing Communications Satellites





Inclined Orbit Operations Without Comsat Maneuver



Inclined Orbit Operations With Comsat Maneuver

Fig. 10-11. The effect of the Comsat Maneuver on inclined orbit operations, exaggerated for illustrative purposes.

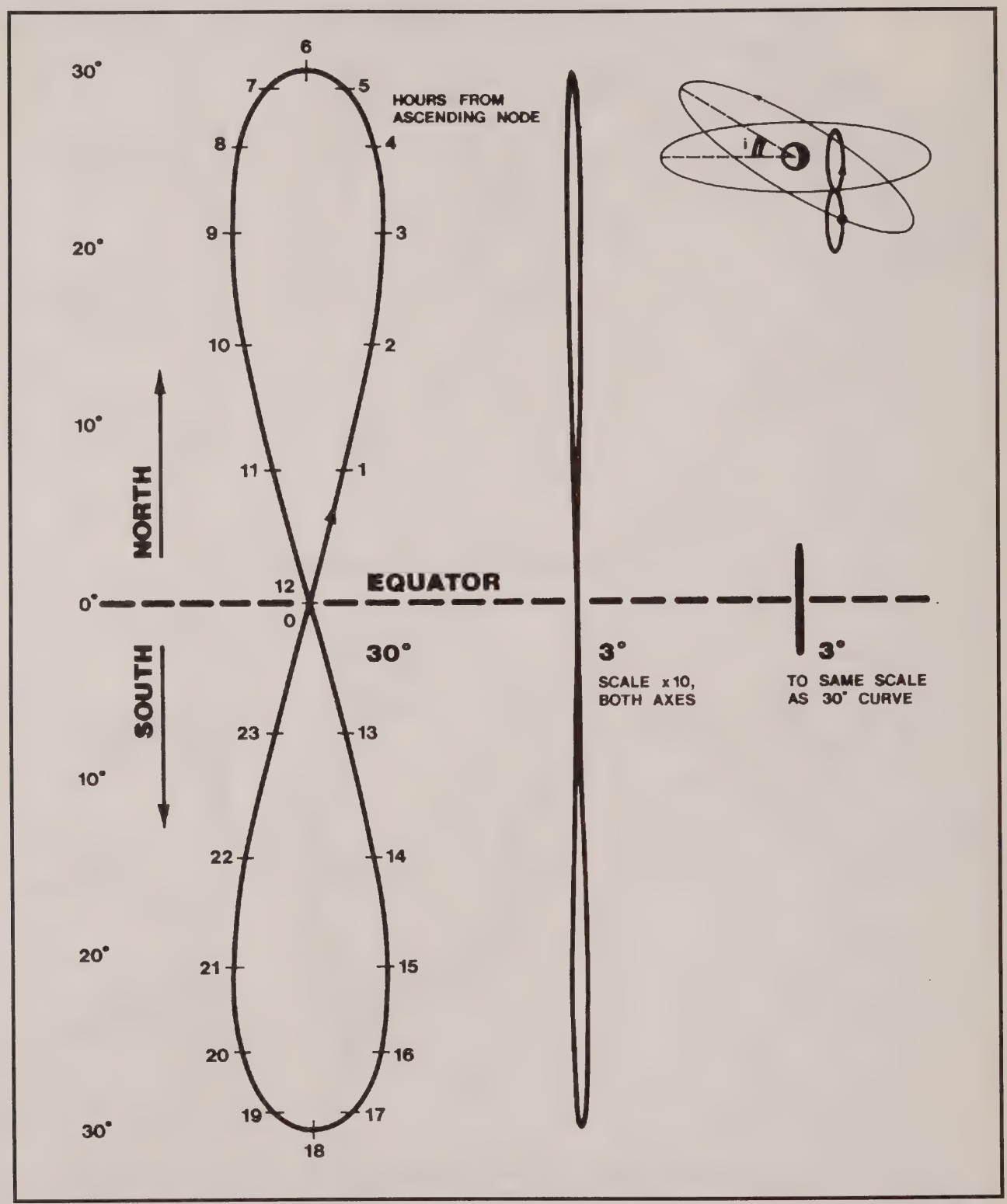


Fig. 10-10. As viewed from the ground, the inclined orbit describes a figure eight type of motion with the satellite North of the Equator for twelve hours and South of it for twelve hours. The width of the figure eight is very small which, for low values of inclination, appears to be a line which lies perpendicular to the satellite arc. (Courtesy Stephen J. Birkill.)

directly related to the extent of the satellite's orbital inclination. At high orbital inclinations, this can be a significant factor—especially for the smaller, more concentrated Ku-band satellite spot beams—and must be taken into consideration when planning the design of the satellite receiving system.

Limitations of the Comsat Maneuver

Because there will remain a certain degree of beam movement over the course of each sidereal day—resulting in some variation in the downlink signal's effective isotropic radiated power or EIRP—it is extremely important that a margin of several dB in receive system carrier-to-noise or "C/N" be factored in to the design on the satellite earth station to compensate for the worst case performance of the satellite at your location. To illustrate the possible effects of beam shifting, a theoretical beam pointing for the Ku-band East spot beam aboard an Indian Ocean Region INTELSAT V satellite is presented below. With a given inclination of ± 2.5 degrees, saturated beam EIRP would vary between 1.5 and 2.5 dB within the central contours, or even more out towards the beam edge. The illustration provided below expresses the degree of variance through the vertical ellipses over Cairo, Riyadh, and Muscat, assuming a theoretical beam boresight centered on Saudi Arabia. At the time of writing, the Ku-band payload on INTELSAT V F5 was not being used for transmitting telecommunication traffic.

Since orbital inclination would increase at a rate of about ±0.8 degrees per year, the above mentioned variances in EIRP would likewise be expected to increase. The amount of variance would be greater for locations out at the edge of the satellite coverage area, or footprint, than it would be for locations toward beam center. The amount of variance, whether the Comsat Maneuver was being used or not, also would be greatly affected by the type of satellite beam in use.

Beam Patterns and Inclined Orbit Satellite Reception

All communications satellites carry one or more types of beam antennas: global, hemispheric, zone and spot. For many of the international satellites, the type of beam can be selected by ground command for maximum

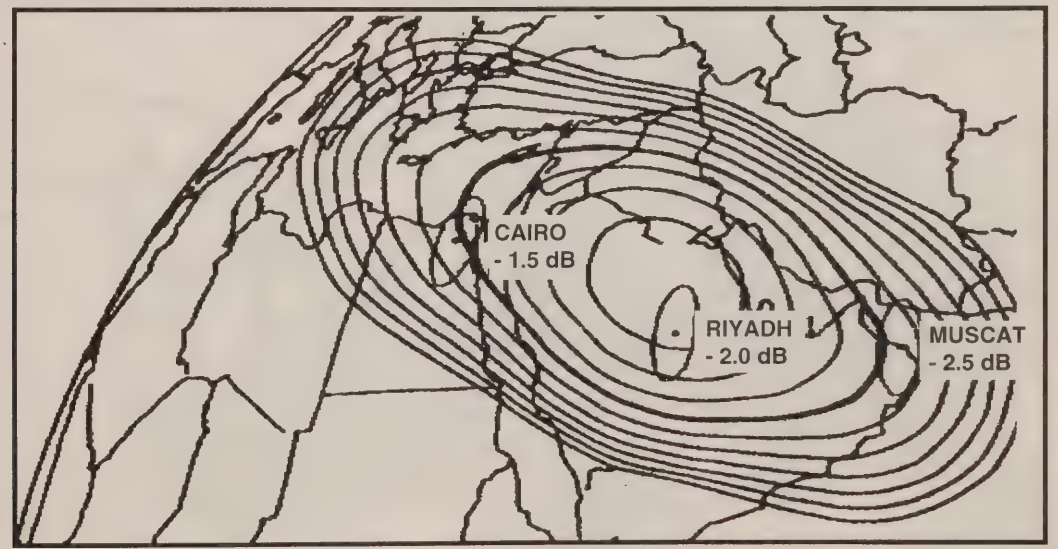


Fig. 10-12. A theoretical example of the amount of EIRP variance which would occur at Cairo, Riyadh, and Muscat for the Ku-band East spot beam aboard and Indian Ocean Region INTELSAT V satellite with an orbital inclination of ±2.5 degrees.

versatility. The overall effect of inclined orbit operations depends on the type of beam in use.

Global Beams. Global beam EIRP is the least affected by inclined orbit operations because the distance between contours is so great, and the change in EIRP from contour to contour is only 1 dBW. Sites located at the extreme North or South of the coverage pattern would be most affected.

Hemispheric and Zone Beams. For locations towards the edge of the beam patterns, Hemispheric and zone beam EIRP will vary more for the INTELSAT than for the STATSIONAR satellites because the contours are more closely spaced for the INTELSAT beams than for the STATSIONAR beams. Again the amount of variance will be the greatest towards the edge of the beam coverage area.

The relatively wide distance between contours of the Russian STATSIONAR satellite beams is due to the fact that these footprint patterns were expressly designed to accommodate inclined orbit operations. While the Russians have long excelled at the technology of launching communications satellites, only recently have their satellite engineers been able to design spacecraft which are light enough to be able to carry the required amount of stationkeeping fuel to permit full geostationary operations for more than a two to three year period.

Spot Beams. Many international satellites and all domestic satellites carry more concentrated spot beams. Spot beam reception is more affected by the signal variance associated by inclined orbit operations because the distance between contours is so small. In fact, sites located near the edge of the beam pattern may find that their reception will degrade so much during portions of each sidereal day that normal reception is impossible to achieve.

In the case of the C-band STATSIONAR satellites of the Gorizont class, the high powered C-band spot beams have been designed to work with 1.8 meter (6 foot) "Moskva" downlink terminals. These small aperture receiving antenna have a wide enough beamwidth to allow continuous reception of an inclined orbit Gorizont satellite's spot beam throughout its diurnal range of motion. The amount of variance in EIRP is compensated for by increasing satellite transmission power by several dBW more than what would be necessary for comparable reception from a geostationary satellite.

Fig. 10-13. INTELSAT VII C-band hemispheric and zone (left) and Ku-band spot (right) beam coverage from 66 degrees east longitude..

Antenna Geometry and Inclined Orbit Satellite Tracking

The amount of difference between the direction in which the antenna is pointing—the beam focus or "boresight" of the antenna's main axis—and the actual direction of the satellite is called the "pointing error". For small amounts of inclination, the motion of an inclined orbit satellite appears as a virtual straight line that is perpendicular to the geostationary satellite arc. This line can be tracked by the motorized receiving earth station with a minimal number of pointing errors.

As the inclination of the satellite grows, however, the width of the figure-eight also expands, causing an increase in the amount of pointing error and a corresponding decrease in the amplification factor or "gain" of the receiving antenna. Any decrease in antenna gain can cause a reduction in the overall performance of the satellite receiving system.

There are several factors which influence the impact of antenna pointing error: antenna size or "aperture", the satellite frequency band in use, the type of parabolic curve used by the antenna designer, and the width of the inclined orbit's figure-eight ellipse.

The Effect of Reflector Size on Antenna Beamwidth

The perfect parabolic antenna would create a narrow receiving beam that would only amplify signals emanating from a radiating source located to the front and center of the dish. In reality, every parabolic antenna has its own unique receiving pattern which illustrates how much receive gain will be given to signals emanating from any given direction. This pattern consists of a strong "main beam" located to the front and center of the antenna and lower level side beams or "lobes" which are located to either side.

The main beam of a parabolic antenna is defined as having a "beamwidth" of 3 deciBels (dB)—a logarithimic measurement scale first developed by Bell Labs for discerning minimal changes in the levels of communications signals. A 3 dB beamwidth means that the received signal can vary by as much as 3 dB depending on which part of the main beam is directly focussed onto the satellite. If pin-point accuracy is achieved, then the amount of signal loss due to pointing error would be 0 dB. On the other hand, if only the edge of the main beam is directly pointed at the satellite, then - 3 dB—or

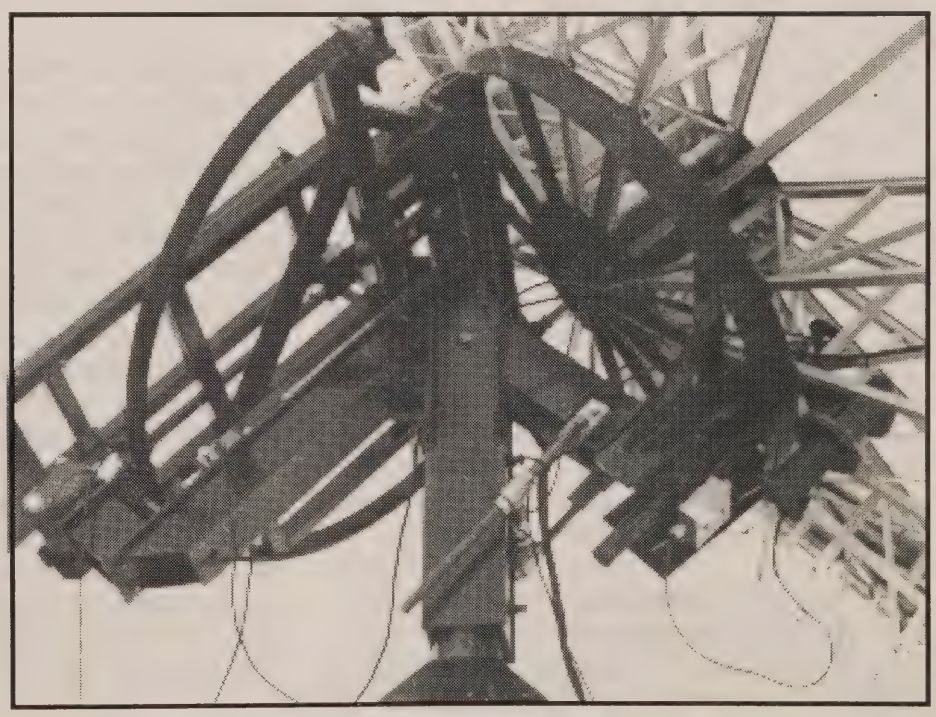


Fig. 10-14. Orbitron's commercial Declination Drive package is mounted onto the antenna arm and attaches to the back of the antenna mounting structure. (Photo courtesy of Orbitron).

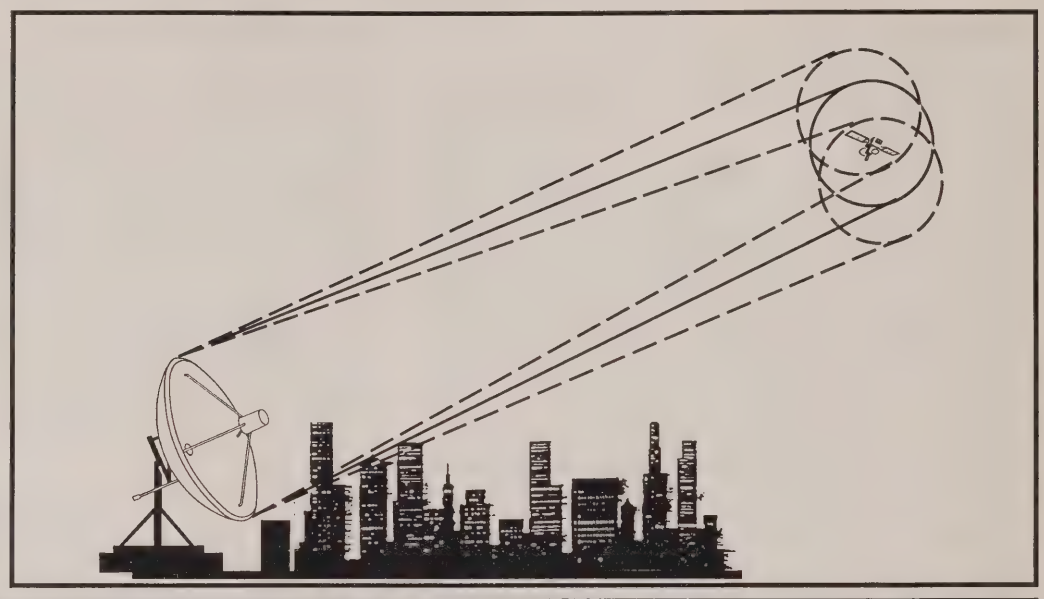


Fig. 10-15. The solid-line circle illustrates antenna boresighted onto the satellite with no pointing errors; the broken-line circles show that pointing errors have occured, but the satellite still falls within the 3 dB contours of the antenna's main beam.

half of the incoming signal's power—would be lost!

As the diameter of an antenna increases, the beamwidth becomes more narrowly focussed. A tighter beam means that even small inaccuracies in antenna pointing can result in a significant change in the level of the received signal.

Antenna Reflector Design

Depending on the nature of the parabolic curve selected by the antenna designer, the depth of any dish can vary between extremely "shallow" to very "deep", or various points in between. The beamwidth for any parabolic antenna of a given size or "aperture" is directly affected by whether a deep or shallow dish design is employed. With a deep dish, the focal length—the distance between the feedhorn/LNB assembly and the inner surface of the reflector—is relatively short, while shallow dishes have a longer focal length which positions the feedhorn and LNB a greater distance from the center of the dish. Deeper dishes will have a narrower beamwidth than shallower antennas for a given antenna aperture.

The Effect of Frequency on Antenna Beamwidth

As the frequency of the received signal increases, the focus or 3 dB beamwidth of the antenna decreases, which is why an antenna will focus more narrowly when receiving Ku-band signals—and therefore experience a greater reduction in gain for a given amount of pointing error—than when receiving C-band signals. To reduce the amount of pointing error, a Ku-band receiving antenna will have to track the inclined orbit satellite more precisely than a C-band antenna of equivalent size.

The Width of the Figure-Eight Orbit

The diurnal motion of an inclined orbit satellite traces an elliptical "figure 8" pattern in the sky. The precise dimensions and orientation of the ellipse depends on the geographical location of the receiving earth station relative to the satellite and the degree of orbital inclination.

To precisely track the motion of the inclined orbit satellite through its 24-hour sidereal day, antenna pointing must be periodically adjusted to follow the satellite's movement. "Azimuth" and "elevation" are the two basic coordinates used to determine an inclined orbit satellite's precise position in the sky at any point in time. The azimuth coordinate represents the compass bearing of the satellite (corrected to true North) from the site location, while the elevation is the angle at which the dish looks up at the satellite.

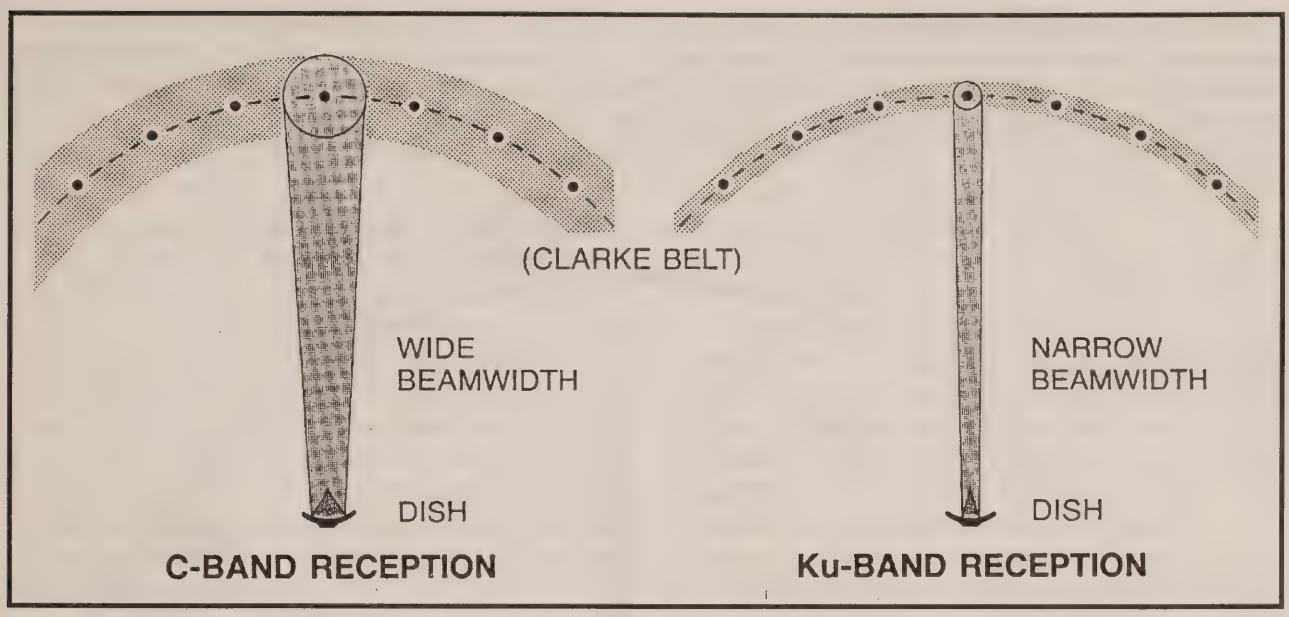


Fig. 10-16. The effect of frequency on antenna beamwidth.

For satellites located nearly due North or South of the receiving site, the apparent satellite motion is a thin vertical figure-8 pattern and the required tracking motion of the antenna is nearly all in elevation. For antenna locations which lie East or West of the satellite's longitudinal position over the Earth, the figure-8 pattern tilts from vertical while remaining essentially perpendicular to the satellite arc.

As the difference in longitude between the receiving site and the satellite increases, the required tracking motion for maximum reception acquires greater amounts of azimuth. When the two longitudes differ by a large value, i.e. the satellite is located relatively near to the site's Eastern or Western horizons, the main tracking motion will be in azimuth.

Minimizing Antenna Pointing Error

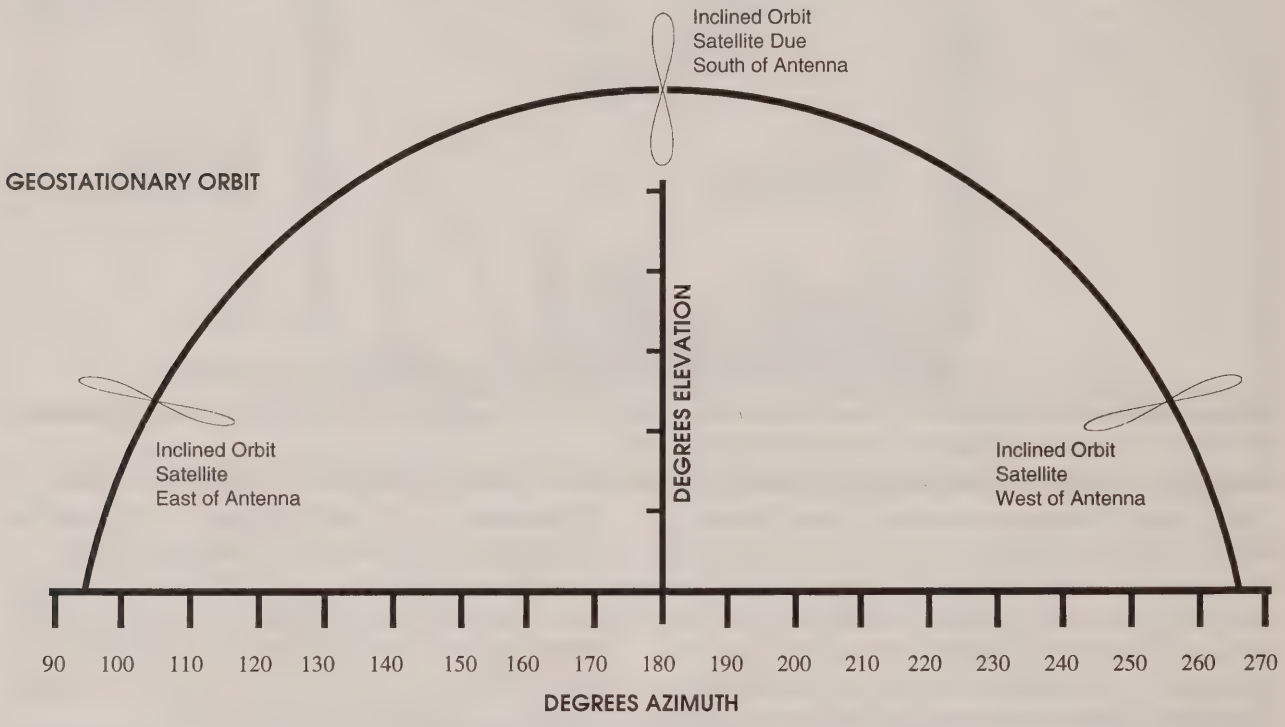
Satellite system manufacturers try to maximize the incoming signal strength while keeping external and internal noise to a minimum. This relationship is expressed as the Carrier To Noise Ratio (C/NR). Every receiver has a threshold point (expressed in dBs C/NR). When the C/NR falls below this point, the video rapidly becomes noisy. Once the C/NR is a dB or more above threshold, impulse noise or sparklies" disappear.

It therefore is extremely important to keep the satellite system operating above the receiver's C/NR threshold. The amount in dB that the system must exceed this threshold in a TVRO system is governed by whether the earth station is dedicated to providing home satellite TV, Cable TV, or broadcast TV services.

One way to counteract the adverse effect of antenna pointing error is to factor a signal safety margin of 3 dB in carrier-to-noise ratio (C/NR) into the design of the receiving system. Therefore the earth station will receive sufficient signal for adequate operation as long as some portion of the main beam remains pointed at the satellite at all times. This 3 dB margin is commonly achieved by selecting a receiving antenna with a larger aperture. For example, a 4-foot C-band antenna can produce a "gain" of 32.5 dB (70% efficiency), while a 6.5-foot C-band antenna can produce a gain of 35.5 dB (70% efficiency). Keep in mind, however, that the antenna tracking mechanism must be accurate to maintain pointing within the antennas 3 dB beamwidth for this to be an effective strategy.

During the first few months following the inception of inclined orbit operations for a given communications satellite, the amount of movement will be insufficient to take the location of

Fig. 10-17. For satellites nearly due South (or due North for locations South of the Earth's equator) of the receive site, the apparent satellite motion is a thin vertical figure-8 pattern and the required tracking motion of the antenna is nearly all in elevation. If the antenna is East or West of the satellite the figure-8 pattern is tilted from vertical while remaining essentially perpendicular to the satellite arc. As the satellite and receive site differ more in Longitude, the required motion is in both azimuth and elevation. When the two Longitudes differ greatly, the tracking motion is nearly all in azimuth.



the satellite outside of a small aperture antenna's 3 dB beamwidth. If sufficent margin has been calculated into the design of the earth station, then there will be no adverse effect on system performance.

However, eventually the satellite's movement will increase to a level that does take the satellite outside the receiving antenna's main beam for significant portions of each day. At this point, the receiving antenna must be equipped with a tracking mechanism if the satellite is to be continuously received. Two different types of motorized tracking systems commonly are available: single axis and dual axis. The type of tracking system used will depend on the kind of mount which the receiving antenna has and the level of tracking accuracy which the antenna must achieve in order to maintain the required level of performance.

Antenna Mounts and Inclined Orbit Tracking

Az/El mounts. Most small aperture voice and data communications antennas and larger commercial grade antennas are equipped with Az/El mounts. Antennas on Az/El mounts can be moved in either the azimuth (East/West) or elevation (up/down from the site horizon) directions. If the antenna is situated within approximately ± 5 degrees of the satellite's longitudinal assignment over the Earth's equator, the inclined orbit satellite will appear to be moving in elevation only. In this case only the elevation axis needs to be motorized for tracking through the center of the figure eight motion of the satellite and a less expensive single axis controller will be all that is required. At all other locations both axes will have to be motorized for Az/El mounted antennas to track inclined orbit satellites accurately.

Several manufacturers with dual-axis an-

tenna controllers are listed later in this book. It should also be noted that manufacturers of extremely large commercial antennas (7 meters on up) provide Az/El mounts with both axes motorized so that even geostationary satellites can be precisely tracked as they move within their assigned +/- 0.1 degree "orbital box".

The "Modified" Polar Mount. An offshoot of the True Polar Mounts long used by astronomers for pointing their telescopes at celestial targets in the sky, "modified" polar mounts are used by earth stations which commonly receive more than one communications satellite (See Chapter 9 for further details on modified polar mount alignment). These mounts track the satellites along the geostationary arc by means of a single East/West adjustment in direction called the "actuation".

Because of the relative closeness of satellites as opposed to the stars and planets, the modified polar mount must have an axis which is inclined a fraction of a degree toward the Equator from parallel to the polar axis of the Earth. It is this parallelism which calls for the quotation marks surrounding the word "modified" preceding the word polar. To observe satellites in geosynchronous orbit, satellite antennas are further tipped from their mount's modified axes toward the equator by a small angle which is called the "declination".

The modified polar mount used for receiving geostationary satellites has a single motorized actuator which moves the antenna in the East/West direction. This type of mount can be retrofitted for inclined orbit tracking by replacing the mount's fixed elevation adjustment rod (or turnbuckle) with a second motorized actuator arm so that the antenna can be adjusted in both the East/West and Up/Down directions. However, unless the antenna is located at virtually the same longitude as the satellite to be tracked, movement of the antenna is required in both East/West and Up/Down directions for optimum reception.

A more accurate modification to the modified polar mount is to motorize the antenna's declination axis. A single movement in declination will point the antenna virtually up the middle of the figure eight ellipse. As we have noted earlier, the figure eight movement of the satellite is perpendicular to the geostationary arc. Once the antenna has been moved to the East or West along its polar axis to the correct "hour angle" setting for the satellite, movement in the antenna's declination axis also will be at right angles to the geostationary arc.

Unfortunately, many of the lower-cost home satellite TV antennas being manufactured today have a fixed declination adjustment inserted between the parabolic reflector and the modified polar mount. All too often, this fixed declination adjustment is not easily motorized. Therefore, a new bearing axis may need to be installed in place of the fixed declination adjustment before a motor can be added.

It is less costly, and therefore most desirable, to be able to track the satellite using movement on only a single motorized axis. By causing the antenna to track through the center of the figure eight, pointing errors due to the width of the figure eight will occur.

Tracking At Low Elevation Angles

Whenever an inclined orbit satellite appears at a location in the sky which is relatively near a given site's Eastern or Western horizons, the receiving antenna must be tilted almost on edge in order to receive the incoming signal. Satellite receiving antennas which operate at low elevation angles are more susceptible to performance degradations caused by the high noise temperature of the Earth itself. Since the antenna is tilted toward the Earth, the high noise temperature is "seen" by the antenna along with the incoming satellite signal. The preceding chart illustrates that at low look angles, minor changes in elevation can cause a substantial rise in the noise temperature of the receiving system, thereby degrading system performance.

INTELSAT, for example, sets the effective antenna elevation limits for its earth stations at 5 degrees (C-band) and 10 degrees (Ku-band) above the local horizon for any given geostationary satellite. Keep in mind that an inclined orbit satellite that requires a 5 degree (C-band) or 10 degree (Ku-band) antenna elevation angle when it crosses the equator may actually dip

substantially below the 5 or 10 degree limit for major portions of each 24-hour sidereal day. In extreme cases the inclined-orbit satellite may even drop so close to the horizon that there is a complete loss of service.

Other Limiting Factors

There also are several incidental limiting factors which have a minimum impact on TVRO installation, but a rather more substantial impact on the transmission of voice and data signals via satellite. These include polarization isolation, the doppler effect, and the pointing accuracy of commercial VSATs and extremely large international gateway earth stations.

Polarization Isolation. Almost all communications satellites maximize their use of the limited frequency spectrums assigned for satellite communications by overlapping the channels or "transponders", with signal polarization switching from one sense of polarization to the opposite sense every other transponder. Most domestic communications satellites use linear polarization, where the transmitting satellite radiates the signal in either a relatively vertical (straight up and down) or horizontal (lying flat) polarization as seen from the satellite. Many international satellites—including those operated by INTELSAT and Intersputnik—as well as all high-powered DBS satellites, use an alternate polarization format known as circular polarization. Instead of beaming the microwave energy along a "linear" plane, whether vertical or horizontal, circular polarization is transmitted in a helically rotating pattern, rotating either in a clockwise (left-hand circular) or counterclockwise (right-hand circular) direction as seen from the satellite.

As the pointing error increases, the isolation between transponders of opposite polarization decreases, thus causing the antenna to both transmit and receive more interference from oppositely polarized transponders on the same satellite.

The movement of a satellite along its inclined orbit can induce minor changes in the orientation of signal polarization as seen from locations down on the ground. For TVRO applications, however, it has been found that these moderate changes in polarization actually have little effect on the received signal. In cases where the picture may become degraded, a simple adjustment, either manual or automatic, of the receiving system's polarization setting or "skew" can re-peak the signal.

The Doppler Effect. Similarily, doppler frequency shift—the effects of a delayed signal when transmitting to and receiving from a moving satellite—only has a slight effect in TVRO situations.

Large Aperture Earth Station Pointing Accuracy. Pointing accuracy for large commercial antennas at teleports or even for smaller VSAT (very small aperture terminal) voice and data networks is much more critical than for home TVRO systems. INTELSAT and other commercial satellite operators must operate under much tighter tolerances than those designed for other applications. For this reason a wide range of satellite tracking systems are on the market. These systems vary greatly in size, method of operation, and price.

Antenna Control Units (ACUs)

Antenna motor controllers which can move the antenna either along one or two mount axes but do not automatically track the movements of the satellite are refered to as "manual" positioners, while "automated" positioners use computer microprocessors to keep track of the precise location of the satellite in the sky at any given time.

The Monopulse Tracking System. "Monopulse" position controllers use the satellite signal to keep track of the satellite's position. Positioning information is obtained by "differencing the output of feedhorns which are offset from the focus of the antenna, or by sensing asymmetric waveguide modes in a single feed horn. If the antenna is pointing directly at the satellite the difference signal should be zero." When it senses a difference in signal strength from one to the other it signals the dish to move to re-establish a balance. Although monopulse controllers can be highly accurate and be used to track fast moving satellites, they can be very expensive because they require up to four feedhorns, LNBs, and receivers. The

monopulse system also has a tendency to move the antenna continuously during certain atmospheric conditions which cause signal fluctuations. This unnecessarily increases the wear on the drive mechanism.

The Steptracking System. A steptrack system periodically moves the antenna in small increments in each direction while correlating the received signal level with the antenna's position. After searching within this box and locating the position where the signal is the strongest, the antenna is moved to the position

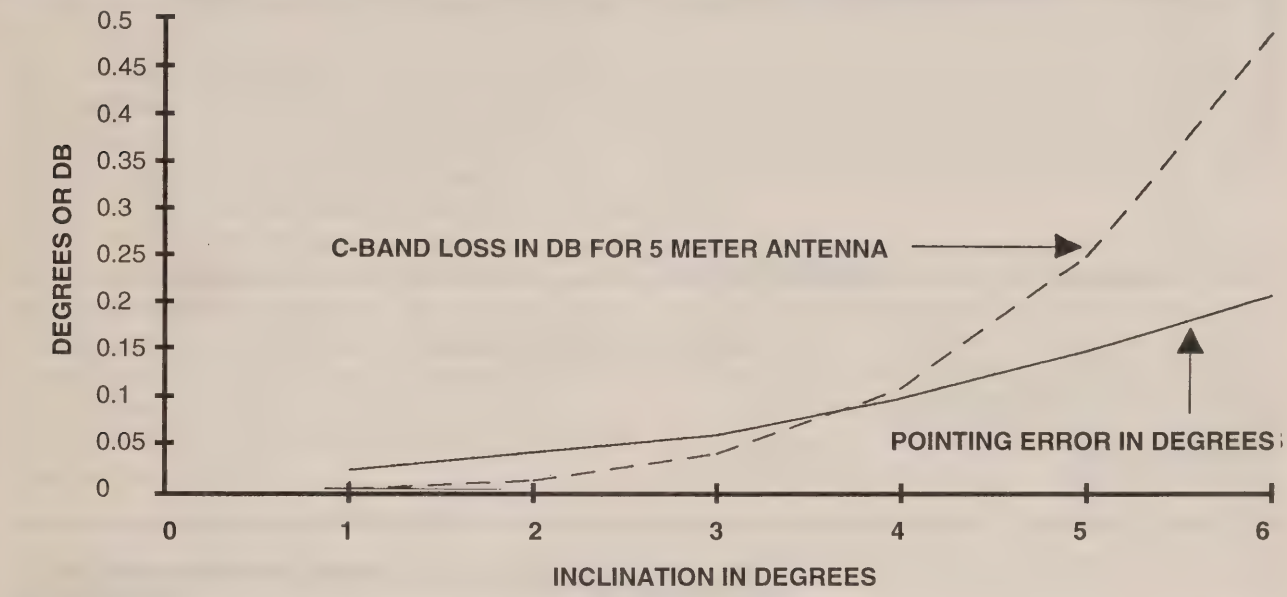


Fig. 10-18. The loss in decibels for a five meter C-band antenna - less than one half dB even for a large degree of inclination. (Courtesy of Merrimac Satellite.)

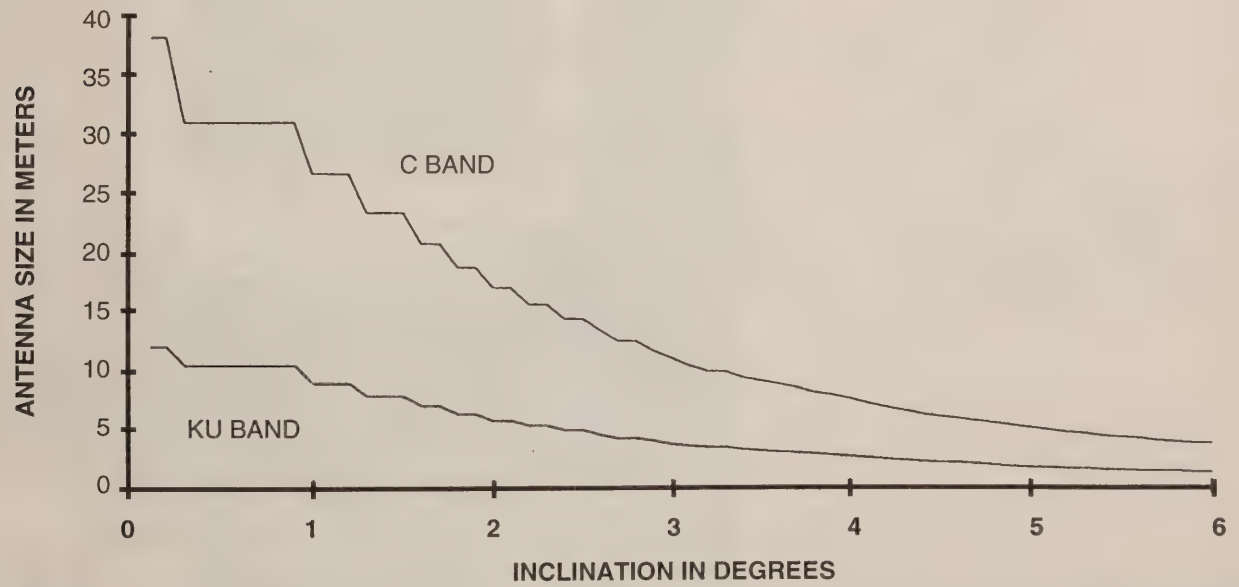


Fig. 10-19. The maximum antenna size allowable for less than 1.5 dB loss due to pointing errors at both C and Ku band. It can be seen that, except for very large antennas or very large orbit inclinations, the worst case losses due to single axis tracking will be minimal. (Courtesy of Merrimac Satellite.)

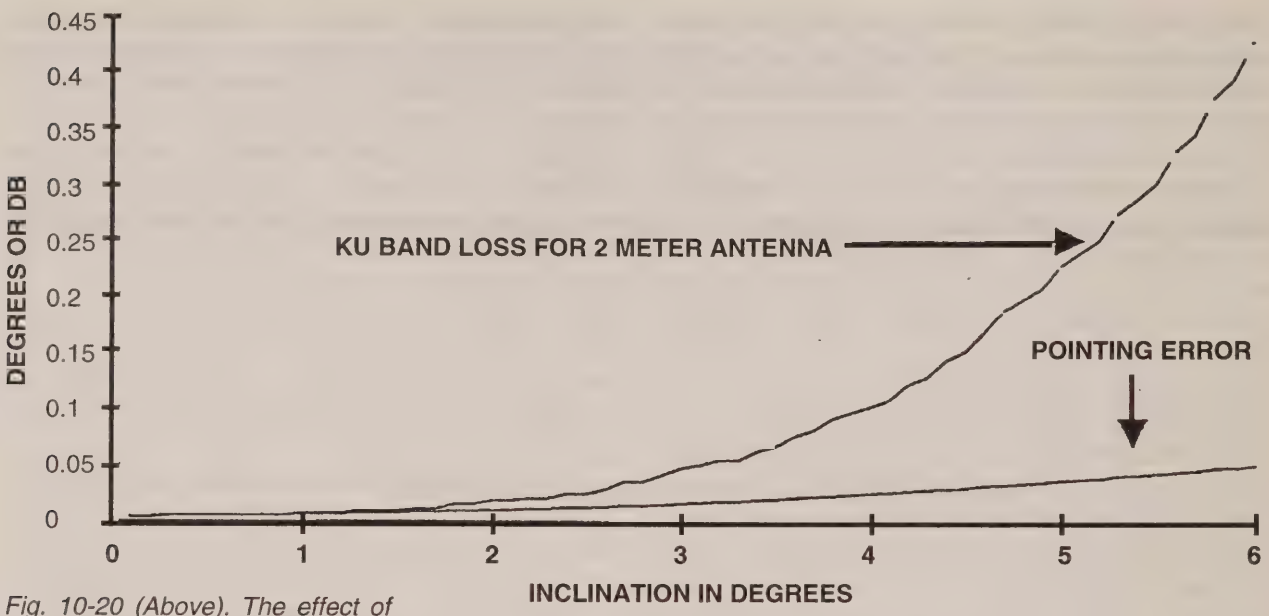


Fig. 10-20 (Above). The effect of inclination on single axis tracking—worst case values. (Courtesy Merrimac Satellite.)

Fig. 10-21 (Right). Merrimac MS-1 Inclined Orbit Tracking Terminal. (Courtesy Merrimac Satellite.)

of strongest reception where it remains until the next search begins. Searches are either initiated after a certain amount of time has elapsed or set to begin when the signal level falls below a predetermined level. This signal level reading is usually supplied by the AGC circuit of the receiver.

Auto peaking with the steptrack system is one of the least expensive and simplest operating tracking modes. For many applications, antennas which offer motorized declination adjustment can do a sufficient job of tracking with this single motorized movement.

The Predictive Tracking System. Because the steptrack system does not have the ability to memorize the positions of the satellites or to predetermine their position, the antenna must go through its searching motions quite frequently. With the self programming "predictive" mode of tracking, however, a microprocessor is added which greatly reduces the amount of searching involved.

Similar to steptracking, the antenna controller peaks the antenna based on received signal strength and then records the position at which maximum signal strength has been achieved. After a definable time period—or when the signal strength falls below a predetermined threshold—a new peak is performed and a new position is recorded. Eventually, the antenna controller has programmed into its memory a "map" of the satellite's orbital movements. By following this map, the controller can anticipate the required movement and automatically initiate the required changes in antenna positioning.

The program is set so that after a certain period of time the tracker will search for a signal peak to verify that it is still tracking accurately. If not, it will start the process of memorizing a new map of the satellite's orbital movements. This is particularly helpful in the case of INTELSAT and Russian satellites, when an older satellite with a high degree of orbital

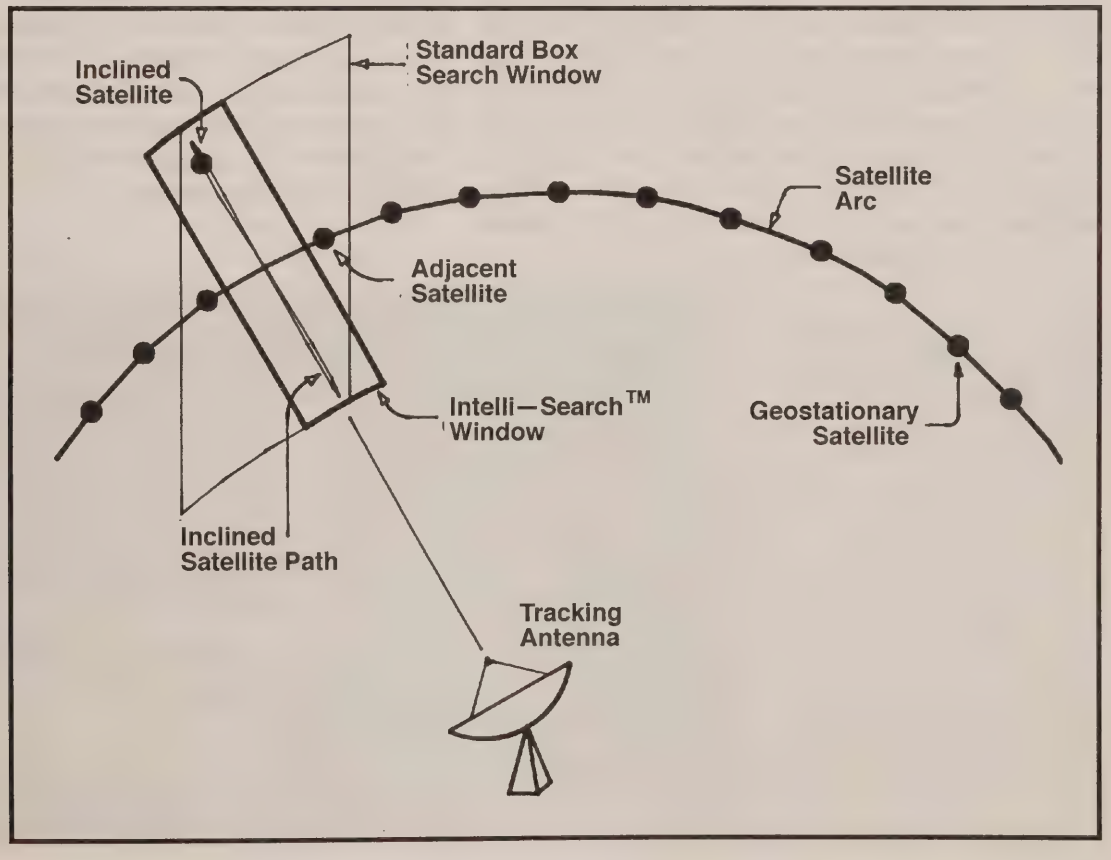


Fig. 10-22. The RC2000B Intelli-Search Advantage. (Courtesy RCI.)

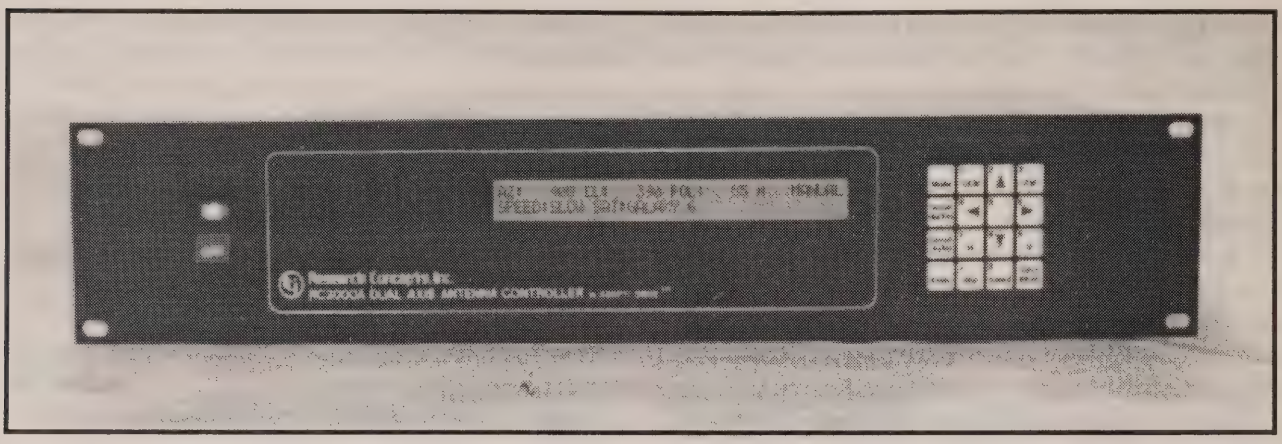


Fig. 10-23. Research Concepts RC2000B Dual Axis Controller features Adapti-Drive. (Photo courtesy Research Concepts, Inc.)

inclination is replaced by a newer with a lower level of orbital inclination.

Program Track Systems. Software programs also can be written to steer the antenna in accordance with the predicted movement of the satellite over time. Since these preset "program track" systems do not rely on feedback from the satellite receiver or feedhorn, the controller will only move the antenna when instructed to by the software program. This saves excessive wear on the positioning mechanism which must be aligned percisely to maintain tracking accuracies. The computer has no provision for confirming it is following the satellite path and the software may have to be updated periodically with new tracking data.

Hardware Selection

There are several different ways that a receiving earth station can be modified to allow continuous reception of inclined orbit satellites. There also are available a wide range of antenna control units (ACUs) and operating software designed for inclined orbit satellite tracking. These different systems will vary greatly in size, price, and tracking accuracy. The application for which the earth station is being utilized will have the greatest bearing on the amount of tracking accuracy required and is therefore the main criteria for selecting the appropriate equipment.

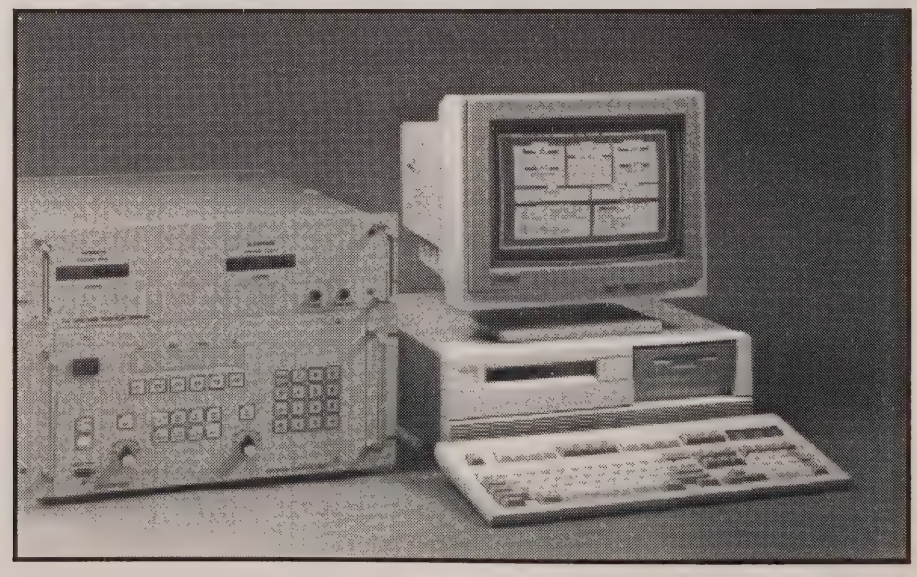
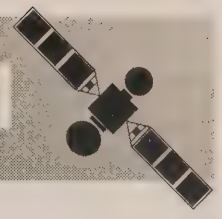


Fig. 10-24. The AC3 Antenna Controller/Tracker. (Photo courtesy TSU Corp.)

Chapter 11



Installing Satellite Master Antenna Television (SMATV) Systems

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The following chapter presents a general overview of the design and installation of private cable distribution systems, also known as satellite master antenna television (SMATV) systems. Although the private cable TV industries in North America and Europe already are quite established, in many other areas of the world, such as Asia, the Middle East and the Pacific Rim, the SMATV market is just now beginning to flourish. It is the intent of this chapter to inform newcomers to the field about the basic technical requirements involved.

Our tour of the various stages of a private cable system will begin with the antenna farm and the "headend" which contains satellite receivers and off-air amplifiers, as well as the signal modulators and combiners. The combined signal output of all signals is then fed into a cable distribution system which supplies programming to multiple locations in a building or to multiple buildings within a given subscriber coverage area. Subsequent sections of this chapter will explain how to design a distribution system as well as how to select and install the various essential components. Readers should refer to the information previously presented in the installation chapter of **The Satellite TVRO Handbook** for further information concerning many of the satellite-related aspects of concern to private cable system installers.

High Time At The Head End

The SMATV system's "head end" serves as the central receiving center of all signals being imported for distribution to subscribers. One or more satellite dishes, as well as multiple off-air VHF and UHF antennas, are used to intercept available programming resources and route the signals into the head end. Designing the head end really begins outside with this important hardware. By determining your programming package, you can then set about the task of selecting the number and types of antennas (both satellite and off-air) needed to accomplish your goal.

The Satellite Antenna Farm

These days with programming spread out over so many different satellites it is almost a given that you'll need to be able to receive signals from several different satellites to get access to all the channels. Sometimes an option to consider is the use of a "multi-feed", a special antenna feed support system that allows you to mount multiple feed horns for the reception of several satellites simultaneously from one dish. However, only one satellite can be received at boresight, where the highest level of signal concentration occurs. The other feeds are picking up signals from other satellites that are not at the prime focus of the antenna but rather are off to one side. Consequently their signal levels are significantly reduced. If a large enough antenna is used, this reduced signal level may still be sufficient to drive a receiver and decoder to produce a sparkle free picture and clean audio. However, there is also the possibility that you'll be dealing with marginal signal levels, not to mention noisy video and audio, which will cause problems with decoder signal authorization. In the long run, if space and finances permit, it is almost always better to install another dish to receive programming from an additional satellite.

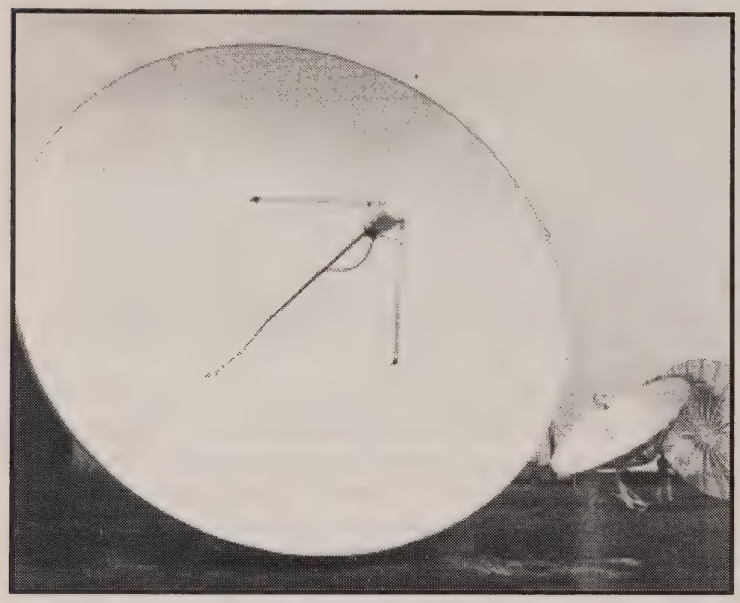


Fig. 11-1. The satellite antenna farm for a small community private cable TV system built by Mark Long, Jeffrey Keating, and Douglas Stevenson. (Photo by Mark Long.)

The Commercial Grade Dish

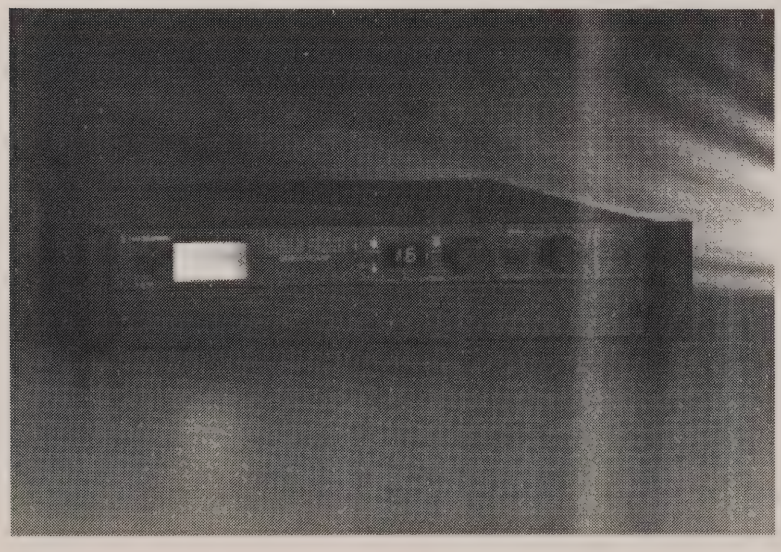
Mass production has brought the cost of consumer grade dishes down quite a bit, tempting many commercial installers to use sub-standard antennas. Commercial grade antennas are more rugged, designed to withstand high winds and inclement weather without a disruption in reception. This is primarily a function of the mount, or supporting structure. If you grab the edge of the dish and pull in either direction, a commercial antenna will show a lot of resistance, barely moving.

Multiple Satellite Receivers

The number of receivers you can have in your head end is virtually unlimited. After all, the design of your system can include multiple dishes—with each antenna pointed at a different satellite carrying dozens of TV channels—as well as equipment racks loaded with commercial satellite receivers, with each receiver tuned to a different satellite service.

Signals from each LNB in the system are split as many times as necessary to accomodate the number of receivers picking up channels from a like-polarized set of transponders on a satellite. Off-air signals received by a terrestrial TV antenna are run to either a broadband amplifier and processor, or multiple single-channel amplifiers and processors.

Fig. 11-2. A rack-mounted commercial satellite TV receiver. (Photo courtesy Standard Communications.)



Video and audio from each satellite receiver is fed directly to a modulator. In the case of encrypted satellite services, if the receiver is an integrated receiver/decoder (IRD), the encrypted video and audio information is decoded and then sent to the modulator, again leaving the IRD as audio and video. If a separate decoder is used, a composite signal from the receiver containing both the encrypted audio and video is fed to the decoder. The decoder unscrambles the audio and video information and sends it on to the modulator as separate signals.

The Off-Air Master Antenna Television (MATV) System

Nearly all SMATV installations will pull some of their channels from local off-air broadcast networks. Unlike satellite reception, which can be depended on to supply perfect audio and video from almost any location with a clear view of the sky, off-air systems can be plagued by a number of problems.

Many of these problems have to do with location. Since broadcast signals travel more or less by line of sight, obstructions such as tall buildings, hills or mountains can actually block the incoming TV signal, reducing signal strength to little or nothing, even though the transmitting tower may be relatively close by. These obstructions also can play havoc with the signal by bouncing and reflecting the signal, creating multiple, out of phase versions of the same program service. Since the reflected signals arrive at the antenna out of synchronization by several milliseconds, they produce trailing images, commonly called "ghosts".

Selecting an Off-Air Antenna

There are two basic types of off-air master antenna television (MATV) antennas available, regardless of whether they are for VHF or UHF TV reception. These are known as Broadband and Single Channel antennas. Broadband TV antennas are designed to receive all of the signals occupying the enitre VHF (Channels 2 - 13 in the U.S.) or UHF (Channels 14 and above) frequency spectrums. Single channel antennas are more selective, cut exactly to measurements that will allow them to resonate strongly with a specific channel, rejecting all others. You must select the type of off-air antenna which will work best at each particular location.

Most broadcast networks transmit within major metropolitan areas. If the head end site is thirty to forty miles to the south of the city, then all terrestrial TV signals will come from a single direction. A broadband antenna pointed to the north will receive all the available channels simultaneously. This broadband signal later can be divided and fed to amplifiers for

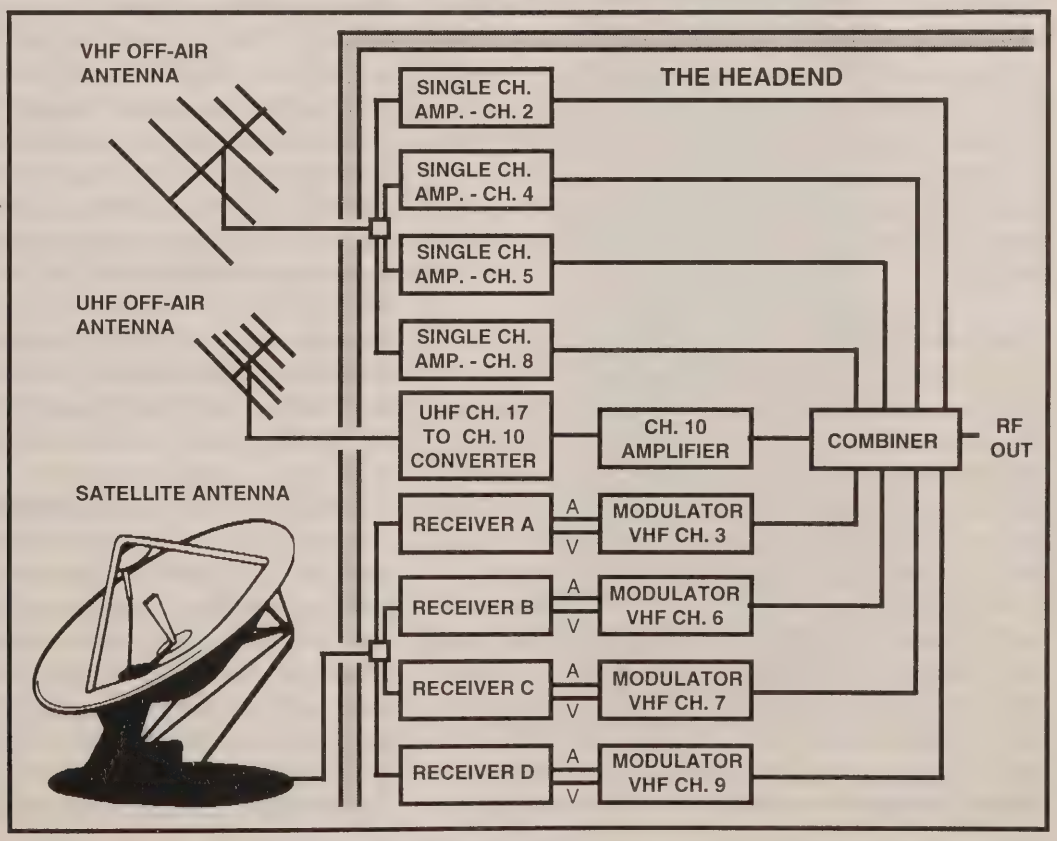


Fig. 11-3. A typical headend providing satellite, VHF, and UHF TV channels.

each individual TV channel.

When installing a system inside city limits, you may find that one TV transmitter is located north of the site location, another to the east, and yet another to the south. In this case, you will need a dedicated, single channel antenna that has been specifically designed to receive each local TV channel frequency.Each of these separate antennas also must be pointed in the direction of the broadcaster's transmission tower.

The Pre-Amp

The further the site is away from the broadcast channel's transmitter, the weaker the signal will be. If the site is located in a fringe area that receives relatively weak signals, a small amplifier, called a pre-amp, should be installed at the antenna to boost the incoming signal to the level that is required by the main amplifier in the head end for that channel.

The Broadband System

The off-air antenna signals are fed to a single broadband amplifier located inside the head end. If you are using a broadband antenna then a single coaxial cable connects the antenna to the broadband amplifer which feeds your distribution system. Whenever the MATV system has multiple antennas, then the signals from each antenna must be combined together onto one cable before arriving at the input of the amplifier.

Single Channel Amplifiers

A preferred installation method can be to supply a dedicated amplifier for each terrestrial TV channel to be carried by the system. Each amplifier is tuned to a specific channel. The system designer therefore must know at the outset which channels will be received by the MATV antenna system.

Whenever the MATV system uses multiple, single-channel antennas, the coaxial cable from each antenna is fed to its corresponding amplifier. A system with a single broadband antenna has a single coax going to the head end. This cable must pass through a splitter, which divides the signal for delivery to each amplifier.

Bandpass Filters

The ultimate goal is for each dedicated amplifier to only boost the signal of one TV channel. Bandpass filters are used to eliminate other irrelevant channels that may otherwise be received and sent down the cable from the MATV antenna to the amplifier. The bandpass filter strips away all irrelevant signals, passing only the one desired channel. Bandpass filters are passive, in that they require no electrical hookup or provide any amplification.

Channel Processors

Processors differ from ordinary amplifiers in that they convert the terrestrial TV channel received from a local broadcaster to another TV channel frequency that has no local off-air channels competing with it. Problems often result whenever off-air channels are sent through the cable distribution system on the same channel frequencies used to transmit the signals through the air. This is done to prevent the phasing problems which cause "ghosts"—trailing multiple versions of the same image that produce a picture that is unacceptable for viewing. This occurs because the TV set picks up the same signal directly from the original off-air transmission as well as the time delayed (by milliseconds) signal passing through the cable distribution system. What the processor does is place the TV signal on an entirely new channel so there is no possibility of multiple versions of the same signal arriving out of phase at the TV set. The main disadvantage to this set up is that the local broadcast networks will appear on channels which differ from the listing in the local newspaper or TV publication. This can be confusing for the new system viewer.

Off-Air UHF to VHF Conversion

Most major cities in the United States have at least one UHF TV channel. UHF frequencies have greater loss when passing through a given distance of coaxial cable than do VHF signals. Most private cable systems convert the UHF channel to a lower frequency channel, generally an unused VHF channel. The complete installation begins with a broadband or a custom tuned UHF antenna and an UHF pre-amp

if the signal needs boosting. The output signal is fed to the UHF converter which strips the video and audio information off of the original UHF channel frequency and places this information onto a specific VHF channel frequency. For example, UHF channel 17 may be converted to VHF channel 10, or UHF channel 35 to VHF channel 6. This converted output is sent to a single channel amplifier and then combined with all of the other channels in the head end.

The Modulator

The decoded audio and video information coming out of the satellite receiver, decoder or IRD is sent on to a modulator. Each modulator has its own RF output, tuned to a single VHF, midband, superband, or in some cases, a UHF TV channel.

The output signals for all of these modulators must be combined together into one single broadband "multiplexed" signal that is then distributed to each of the subscribers connected to the private cable system.

Fixed Frequency Versus Frequency Agile Modulators

One of the best cable innovations in recent years has been the introduction of frequency-agile modulators. Even though most modulators remain dedicated to one single RF frequency for their entire service lives, frequency-agile modulators offer several advantages over fixed frequency units.

Fixed frequency or frequency agile refers to the modulator's tuning. Fixed frequency modulators come pre-tuned to one channel in the VHF, UHF, Midband, or other bands used in cable distribution. Frequency agile modulators can be tuned and/or switched through the entire range of channels.

The electronics in a fixed frequency modulator are less complicated than in those providing multi-channel selection and therefore are usually less expensive. Both fixed and agile modulators have high and low end units, at various price points. A US$ 500 agile modulator cannot be expected to perform with the quality or meet the same specifications as an US$ 800 single channel modulator.

For flexibility, the head end can be designed with a mix, with fixed-frequency units in primary use and one or more fully agile units available as backups for the system. A system like this holds the cost down and gives the operator fully redundant capability for all channels.

The first measurement usually listed in modulator specifications is the output level, measured in deciBels, relative to one milli-volt (dBmV). Medium power commercial modulators have an output of approximately 25 to 35 dBmV per carrier. High power models offer even more. Obviously, the higher the output, the

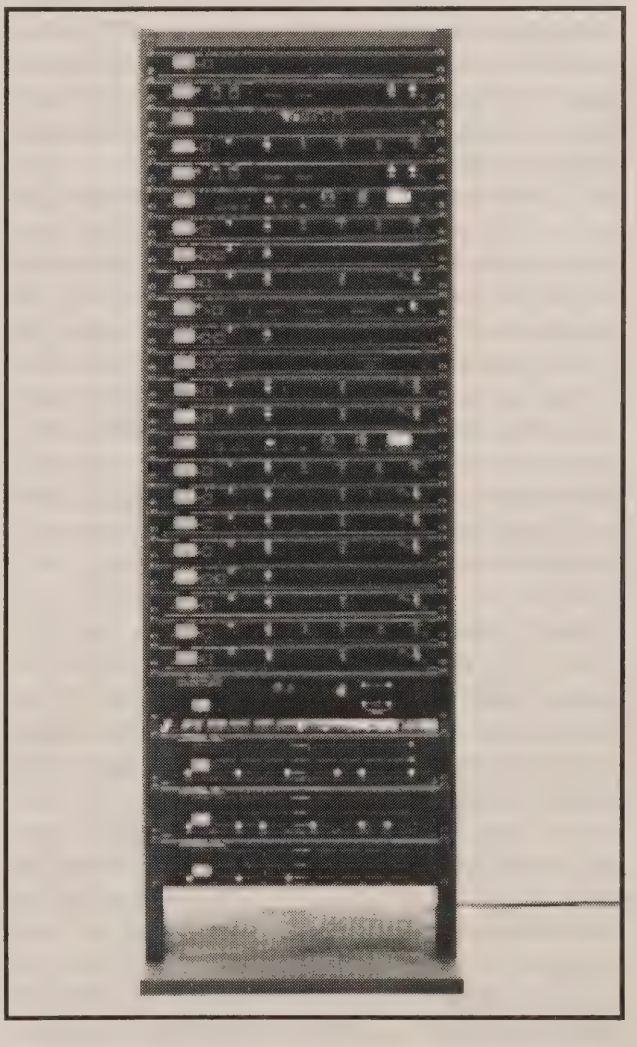


Fig. 11-4. A typical head end rack with modulators (above) and combiners (below). (Courtesy Pico Macom, Inc.)

more TVs it can supply with ample signal, or the longer distance it can travel down a cable before the signal needs boosting.

In contrast, the channel 3/4 modulator usually found in consumer satellite receivers and VCRs generally has an output of about 5 dBmV. That's considered about the ideal amount needed for one TV, although it is enough to permit splitting the signal to feed additional TVs in a household, and still have an acceptable picture on each set as long as the cable runs aren't too long.

The output of the modulator is critical when designing a commercial headend. If you have a twenty channel system with all modulators supplying an output of 55 dBmV you cannot replace a malfunctioning unit with a 35 dBmV output modulator. Since all channels on the TV must appear equally strong and clear, their signal levels must be equalized before leaving the head end.

If the system uses 35 dBmV output modulators, a higher powered modulator such as one with 55 dBmV cannot be used as a substitute unless its output power level is reduced. Attenuator pads can be installed in series with the higher powered modulator's output. These serve to limit or drop the power down to the desired level without introducing impairments. Pads come in a variety of values (3, 6, 10, 20 dB, etc.). They can be mixed and matched until just the right level is found, keeping the outputs of all equipment evenly balanced.

Modulator Filtering

Filtering in the modulator is as critical as setting the power level. For example, if the modulator's output is channel 3, there should be no channel 3 interference or "artifacts" visible on either channels 2 or 4.

One part of the modulator is a single channel amplifier. Amplifiers often produce harmonics and spurious frequencies if the gain is set too high. These can show up as bleed over or "ghost images" on adjacent channels. Harmonics can be a multiple of another frequency and the interference can show up several channels away. An ideal situation would be to leave a blank channel on either side of an active channel to avoid adjacent channel interference. That luxury is most often eliminated by the number of channels to be transmitted and the need to stay away from the higher frequency channels, which are subject to excessive loss over long distances.

External bandpass filters on the modulator output of high gain amplifiers have limited effectiveness. The better modulators made today contain an internal SAW (Surface Acoustic Wave) filter. They do a good job of keeping the RF within the appropriate channel bandwidth and are all but essential for installations where adjacent channel interference is a potential problem to be overcome. The key to success here is to keep power levels balanced. If you have a 55 dBmV modulator on channel 3, and only 35 dBmV on channel 2, signal bleed over on channel 2 is inevitable.

Interference also can be caused by inordinately high audio levels. The audio subcarrier frequency is located near the lower edge of the video waveform envelope. If the audio level is too high, it can bleed onto the next channel down as well as interfere with its own video carrier. Backing down the audio gain will usually correct this kind of problem. To ensure that all audio subcarriers are at the same level, a local off-air station can be used for reference. The technician also can use a dB meter to measure the intensity of the audio subcarrier.

Interference problems also will occur whenever the channel's video level is set too high. Not only will white and other bright portions of the picture appear too "hot", but it also can cause the audio to "buzz". Most modulators have manual adjustments for the audio and video inputs, as well as the output levels, on the front panel.

Combining Off-Air and Satellite TV Signals

There are several ways to combine signals. Each method has its own advantages and disadvantages. A motel with four off-air stations, three major networks and PBS, for example, may want to add one satellite channel. In many motel systems you will find these four signals come from one MATV antenna which feeds into a single broadband amplifer.

Let's assume that all of the off-air stations are located in the VHF band on channels 2, 4, and 5, and 8. This leaves channels 3, 6, 7, 9, 10, 11, 12, and 13 as open slots. To reduce the possibility of adjacent channel interference, try to keep an empty channel between the satellite modulator's output channel and any of the local stations. That eliminates channels 3, 6, 7, and 9 but any one of the four remaining channels (10, 11, 12 and 13) should offer sufficient insurance against adjacent channel interference.

Where is the best place to combine the signals? The answer will depend upon the existing setup, your new equipment, and a little trial and error. However, the final result must be equal signal strength on all channels. Combining channels of different strengths will result in cross channel interference and/or poor quality pictures.

There are two ways to achieve an even balance. One is to mix the signals before the broadband amplifier, then feed the combined signals into the amplifier boosting everything up to a common power level. If the satellite modulator produces an output signal that is stronger than the off-air signals, an attenuator can be used to reduce its power (measured in dBs) to that of the off-air channels. However, a closer match might be obtained by sending the off-air stations through the broadband amplifier, and then combining the amplifer and satellite modulator outputs together. As long as both outputs are kept at about the same signal strength, either method will work adequately.

Since we are only adding one channel and there is an open channel slot between it and any other active channel, we can use an inexpensive combiner. In a case such as this, the most simple and cost effective solution would be a two-way splitter. A common splitter can be installed in reverse to mix signals together. Some units are marked as splitter/combiners. The satellite modulator output is connected to one splitter/combiner "output" and the off-air antenna signals to the other. The "input" now becomes a combined output with all signals present together on one cable.

What if there are two, three, or four or more satellite signals to mix with the off-air? Can a splitter still be used? That depends on how broad or how clean the modulator outputs and the off-air signals are. A quality signal stays within the confines of its assigned channel's bandwidth. A broad signal goes beyond these limits and interferes with channels on either side or more.

Using the channel line up previously mentioned, two signals can be added on channels 10 and 13 leaving plenty of space between stations, and little likelihood of adjacent channel interference. However, as more channels are added and adjacent slots are filled, it becomes necessary to use another device called a combiner.

The difference between a combiner and a simple splitter/combiner is the level of filtering. Combiners are designed specifically for mixing channels and have a built in level of separation. They also are built to take in more signals, anywhere from 6 to 12 inputs, and multiplex them into one output.

Even combiners have their limits. A wide and dirty signal can still appear elsewhere up and/or down the band. If a particular modulator or strip amplifier is too broad, no amount of filtering can rectify the situation.

On most combiners, all inputs are the same. There are some brands and models where each input is labeled for a specific channel or pair of channels. These units have tuning slugs which allow you to adjust each input for one channel which improves the degree of isolation between stations.

Active Versus Passive Combiners

Whenever signals are passed through a combiner, they will experience some loss in output, often in the neighborhood of 10 dB, sometimes even more. Passive combiners merely take multiple signals in and send them back out through the single output. When designing a system, you must plan for this loss, either by accepting the output as it stands, or by bringing it back up with additional amplification.

A few manufacturers have designed their combiners to address this loss by including an internal broadband amplifier. These are called

"active" combiners. They depend on an AC source to power the broadband amplifier, restoring the signals to their original levels. Most active combiners do not incorporate any tuning separation between high-band and low-band channels. Due to its limited power output, it often is necessary to use another amplifier before the combined signal enters the distribution system. For these reasons, many installers prefer to stick with passive combiners. They usually are less expensive because they contain fewer electronic components.

Using Multiple Combiners

If more channels are required than the combiner has inputs, two combiners can be used in tandem. The outputs from two combiners often can be mixed together using the humble two-way splitter discussed earlier. Some head ends even put the output of one combiner into the input of another and treat it as just another channel. Since these channels are going through two combiners, the output power levels on the individual modulators and strip amplifiers must be set correspondingly higher, to compensate for the extra loss.

The output from a combiner is too strong to connect directly to a TV. Many combiners have an attenuated tap off specifically for connection to a monitor.

Loop Through Combining

In some cases, you may be able to combine channels using a method called the "loop through". With this method, the output of one off-air strip amplifier is fed to an input (labeled "loop-through") on another strip amplifier. The output of the second strip amplifier now contains both signals, which can be fed into the next unit.

The loop through will work fine if all signals are clean and power output levels are fairly equal. However, when there is a large variation between channels, or if extra filtering needs to be added due to adjacent channel interference, a regular combiner will be a better choice.

A Question of Balance

No matter which combination you choose, the quality of the output is the bottom line. Balancing each channel for the proper amount of power output is essential to maintain distortion and interference-free video. Have a monitor present at the head-end, so you can immediately see the results of your adjustments. Any amount of interference visible at the headend will be multiplexed every time it is amplified in the distribution system.

In the end, it is the planning of these channel combinations that can make the difference between poor, average, or good performance in a private cable system. The art of balancing channels together into a common output devoid of cross channel interference is the magic that defines the skilled technician.

Set the power output on all of your modulators and strip amplifiers so that they are pretty much equal. For this task, you'll need a signal strength meter, which measures in dBs. In the initial planning and design stage, you should have determined the dB level needed from the head end. The amount of power required can vary depending on whether you have a main power distribution amplifier right after the head end, such as for a larger private cable distribution system, or whether the modulators themselves will supply all or most distribution power, as might be the case in a hotel/motel system.

Solving Cross Channel Interference Problems

With all power output levels equal, no one channel should overpower or "bleed" onto any other channel. On many occasions, however, there still may be some "cross channel" interference—the superimposition of ghostlike images from one channel onto the video of another channel in the system.

Determine which channel is causing the interference by trying to recognize a logo or some other identifying factor. First try to eliminate the interference by turning down the output of the offending modulator or strip amplifier. Sometimes just a small tweak with an adjusting screw driver will take care of everything, removing the interference. If that doesn't solve the

problem, it is possible the strip amplifier itself is being fed an impure signal, which it simply amplifies and passes on through the system. Since you are dealing with single channel amplifiers, the only thing you want going in to them is the signal of the desired channel. Band pass filters are designed to only let one signal through, while blocking out all others. Made for specific channels, band pass filters receive the signal from the antenna, before it gets to the strip amplifier. The filter traps out any signal other than the specified channel.

Although not designed for this task, you can sometimes achieve effective results by using a notch filter. The opposite of a band pass filter, the notch filters trap out specific channels, or frequencies related to the interfering channel. If the channel 6 modulator is putting out an interfering signal that shows up on channel 12, place a channel 12 notch filter on its output. The channel 6 signal will pass through unaffected, but the channel 12 frequencies will be eliminated.

Cross channel interference also can be the result of poorly shielded cables between the various pieces of equipment within the head end. The really careful system designer uses quad-shielded cable to eliminate this as a potential problem source.

You may find that the problem is not caused by cross channel interference at all. An off-air TV channel, for example, with wavy lines running through the picture may be delivering too much signal to the input of its corresponding amplifier. If the site is located many miles from a transmitter site, the signal received can be very weak. Or if the head end is relatively near the transmitter site, the signal level may be quite strong, 25 dB or more. Strip amplifiers are designed to receive signal levels within a range of about 10 to 15 dB. If the incoming signal is stronger than this, the amplifier will be over driven and signal distortion will occur. Signal levels which exceed the recommended input range of the amplifier must be reduced to a permissible level. To reduce the signal level, you must use a balancing accessory known as an attenuator. Attenuators are rated by the number of dB that they will reduce the signal, a range like 3, 6, 10, 12 and 20. Attenuators can be stacked together in different combinations to get just the right reduction in signal.

Carrier Power

To decide what output level is needed for your application, one must first examine the design of the entire system. Determine how many TVs are to be supplied with signal and the distance that signal must travel. A motel with short runs may have just a few TVs, or it may have two hundred TVs or more. A small private cable system in a subdivision or resort complex my have only 100 televisions, but they may be spread out over thousands of feet of cable.

This brings into play the second factor, the distribution system. Modulators in the headend of a small motel may be able to supply enough carrier power for all the TVs without additional booster amplifiers to keep the power at acceptable levels. Once your distances have been determined, it may turn out to be more economical to use 35 dB modulators with additional amplifiers than 55 dB modulators on every channel. Understanding the distances involved and the total system requirements can help determine which modulator is best for the particular application at hand.

The Midband and Superband Channels

Whenever an SMATV system will carry more TV channels than can be accommodated on VHF channels 2 - 13, the system designer must select additional channel frequencies to accommodate the extra channels to be provided. There are nine "Midband" channels placed in a band of frequencies between VHF low-band channel 6 and VHF high band channel 7 and more than thirty "Superband" channels between VHF channel 13 and UHF channel 14.

Most TV sets manufactured for the North American and European markets these days are "cable ready" —that is capable of tuning into the Midband and Superband channels as well as the standard VHF and UHF channels. In most other areas of the world, TV sets may be available with tunable channels which can be adjusted to receive TV signals using Midband and Superband frequencies.

Fig. 11-5. VHF, Midband, and Superband Channel Assignments for North America (Frequency in MHz).

LOW VHF	54 - 60	60 - 66	66 - 72	76 - 82	82 - 88						
TV CH.	2	3	4	5	6						
HI VHF	174-180	180-186	186-192	192-198	198-204	204-210	210-216				
TV CH.	7	8	9	10	11	12	13				
MIDBAND	108-114	114-120	120-126	126-132	132-138	138-144	144-150	150-156	156-162	162-168	168-174
CABLE CH.	A-2	A-1	A	B	C	D	E	F	G	H	I
SUPER BAND	216-222	222-228	228-234	234-240	240-246	246-352	252-258	258-264	264-270	270-276	276-284
CABLE CH.	J	K	L	M	N	O	P	Q	R	S	T
SUPER BAND	284-290	290-296	296-312								
CABLE CH.	U	V	W								

Note: Other channel assignments may be used in various countries of Asia, the Middle East & the Pacific Rim.

HYPERBAND: 300 - 456 MHz (Ch. AA-ZZ)
UHF TV: 470 - 890 MHz (Ch. 14 - 83)

Those subscribers who do not have a cable ready TV, or a TV with the ability to tune to Midband or Superband frequencies, must be supplied with a cable converter box, which tunes into the Midband and Superband channels and converts their signals to a signal that can be displayed on one of the TV set's regular VHF or UHF channels. In this case, all channel selection is done at the converter, or via the converter's handheld control. Many VCRs now offer tuners capable of receiving Midband and Superband cable channels. These VCRS can be used instead of a cable converter box if desired.

Adding In House Channels

SMATV systems are not limited to providing channels from local broadcasters or satellite programmers. Adding your own in-house channel can be as simple as connecting the output of a VCR to one of the modulators at the head end. The VCR's signal is then distributed throughout the private cable system just like any off-air or satellite signal would be delivered. Character generators, often used as message systems, also can be connected to one of the head end's modulators to provide text information to subscribers over one of the cable TV channels. A separate source, such as a local radio station, can use the TV channel's sound circuit while the text information is being displayed on each TV screen in the system.

The Cable Distribution System

Once the broadband muliplexed signal carrying all of the desired TV channels leaves the head end, the signal must be divided or "split" several times before it reaches every TV set in the cable distribution system. Each time that the signal is divided, the signal level is reduced at that point in the system. Cable amplifiers must be added at various points along the cable line to boost the signal level back to an acceptable level.

An apartment complex, for example, may have an amplifier for every building or every few buildings, depending on the length of the cable run and how many TV outlets it has to feed. Cable systems which handle whole cities may have hundreds of amplifiers. On small private cable systems, these amplifiers are called "line extenders".

The layout for large distribution systems often is designed by an engineer, who prepares a set of plans called a "strand map". The strand map depicts the interconnection of the cable lines, amplifier locations, and the TV signal outlets. The engineer looks at the entire system, calculates the cable loss and the number of TVs involved.

Hardline Versus RG6

In smaller systems, such as at a hotel or motel, RG6 coaxial cable with a center conductor and an outer aluminum foil shield often is used as the main distribution or "trunk" cable. The excessive loss of RG6, however becomes noticeable over long distances and amplifiers will be required at periodic intervals to boost the signal level back to an acceptable level.

When designing for a small subdivision or any system requiring cables of great length, the coaxial cable used is much larger, generally about half an inch in diameter.

Larger installations use a lower loss "hardline" cable with the solid aluminum outer shield. Hardline cable is stiff and somewhat difficult to work with. It must be handled carefully to avoid kinking, which will cause anything from an immediate short to signal reflections that create ghosts on the connected TV sets in the system.

Hardline cable requires its own special connectors and tools for installation. Although it is flexible enough to make gentle curves in a ditch, sharp 90 degree bends must be done using right angle connectors. There also are special splice fittings, male input, and housing to housing connectors, or even connectors for converting hardline to a standard female "F" connector. There are several brands of hardline connectors to choose from, with each requiring a different preparation technique during the installation process.

Systems which feed entire cities generally run their cable in the air suspended from the electric or telephone poles. Most private cable systems install their cable underground, a more aesthetic approach that does not require the leasing of space on local utility poles.

Underground cable is coated in a black plastic jacket. Between the jacket and the aluminum is a sticky substance that can best be described as a gooey mess! Although it does prevent moisture from entering the cable and causing problems, some kind of solvent will be needed to remove it from the installer's hands.

When it is time to tap off some signal, add an amplifier, or add a splitter, the cable comes up out of the ground and into a green metal enclosure called a "pedestal". These come in large and small sizes, depending on the amount of equipment they are to contain. A big pedestal may hold an amplifier, a splitter, and or combinations thereof. A latch on the front is provided for a padlock. Pedestals are vented to dissipate heat and prevent moisture from affecting the electronics.

Selecting a Distribution Style

Whether you are designing your own distribution system, or working from a plan provided by an engineer, it pays to be familiar with the different styles or ways of sending a signal to multiple TVs.

The Home Run Method. Probably the simplest method is called the "home run". Here the cable for every single TV comes all the way back to a single distribution point, usually at the head end. You usually will find that the home run method is used for serving small systems with just a few TV sets. The advantage of the home run method is that fewer splice points are required, eliminating potential points along the cable where a bad connection and loss of signal might occur. The home run method also allows the system operator to easily control which signals are sent to each subscriber—an essential ingredient in any simple pay-per-view delivery system.

The Series Distribution Method. Another method often encountered in older motels is the "series distribution" system. In this case, a single cable leaves the head end, and at every TV along the way, a tiny bit of signal is siphoned or "tapped" off, with the cable continuing on its journey to the next TV set in the system. The cable may zig-zag up and down from the bottom floor room to the top, and then head back down again. Series distribution systems involve a lot of connections and therefore there are many potential points for problems to occur. This method has almost been entirely phased out of use.

The Trunk and Feeder Method. The most common technique in use today by private cable systems is the "trunk and feeder" method, also sometimes refered to as a "tree and branch" system. A main trunk line—usually half inch

hardline or larger—carries the multiplexed signal from the head end all the way to the end of the line. Along the way, feeder lines are split off from the main trunk, with each feeder line carrying enough signal to satisy the TVs on that branch. Each feeder line actually can supply a great number of TVs, with amplifiers or line extenders added as needed to complete each feeder line off the main trunk.

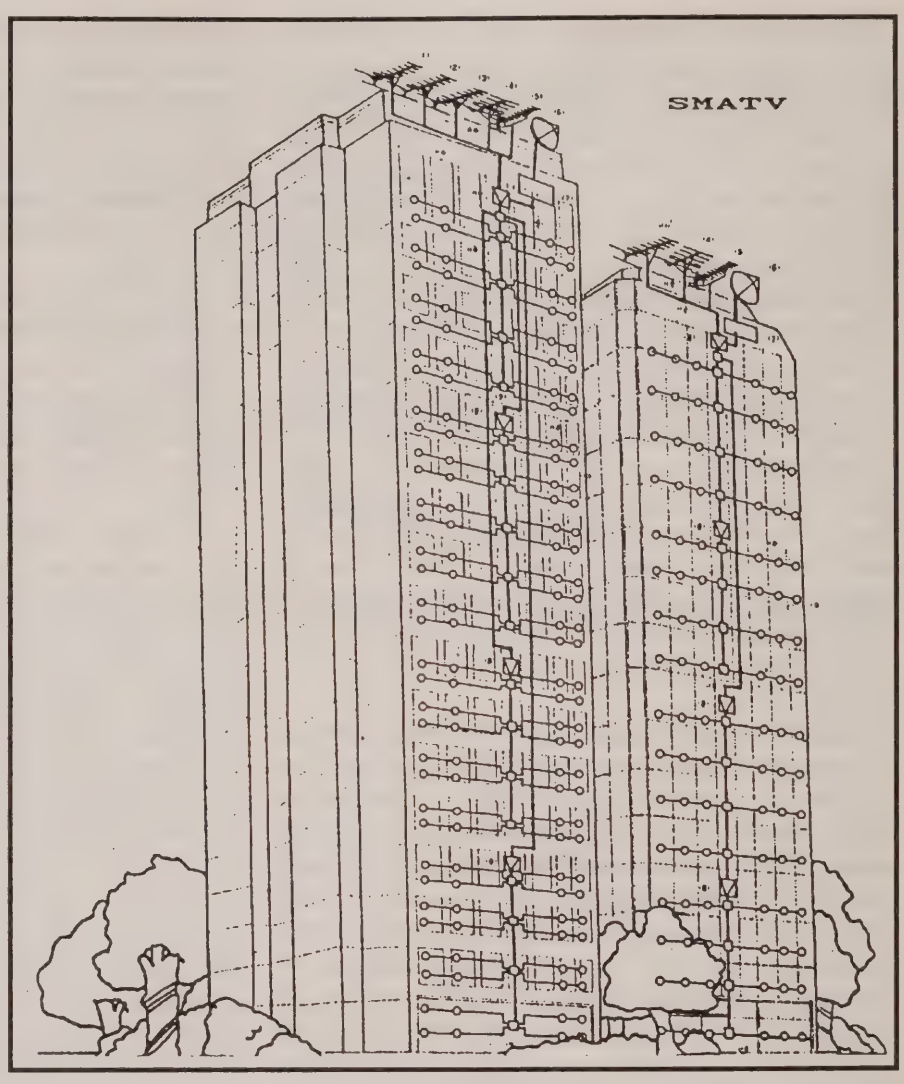


Fig. 11-6. SMATV distribution system layout for a large apartment complex. (From The World of Satellite TV, Thai-language edition).

Amplifiers Need Power!

Nearly every distribution system will need some amplifiers to periodically boost the signal down the line. In some cases, electricity will be available at each amplifier location, allowing the amplifiers to be plugged into the nearest AC outlet. This is done often in hotel/motel systems, or even in systems serving apartment buildings. The use of AC powered amplifiers, however, is only practical when there is one central electrical system that is controlled by the building or system owners.

More often, the amplifiers must be powered remotely, through an AC voltage that is carried piggyback on the distribution cable right along with all the TV signals. A power supply at the head end produces the 30 to 60 volts AC required to power all of the amplifiers in the system.

A power inserter is required before AC power can be put onto the cable. The power inserter has a small rectangular aluminum housing, with ports marked RF IN, AC IN, and RF/AC OUT. Each input and output inside the power inserter is fused as a safety precaution, and to give greater control over the flow of electricity. The fuse on the RF input should be removed prior to applying power so that no AC can find its way back into the rack of equipment.

Tapping off the Signal

The signal level on the main trunk's hardline may be around 45 dB. To deliver 10 dB of signal to one of the TV sets in the system, 10 dB of signal must be siphoned off the trunk line while sending the remaining amount of signal to other subscribers down the line. A power splitting device called a "tap", which is like a water valve which is only partially open, is used to

divide the signal into two or more streams.

Taps are rated in dB. With 45 dB of signal on the line and 10 dB needed at the TV, you would install a 35 dB tap. At the female "F" fitting on the tap there will be a signal output of 10 dB, with the remaining 35 dB going down the line to the next tap location. Although a few dB may be lost as the signal passes through the tap and the coaxial cable between the tap and the TV set, there will still be sufficient signal to deliver a good, sharp picture. Keep in mind when determining the tap value, however, that the signal may be split at each subscriber location to feed a second TV in another room. The tap also does the important job of removing the AC voltage from the signal which might otherwise cause damage to the subscriber's TV set.

Installing Hardline Connectors

The installation of hardline connectors requires special tools and techniques. The basic technical points, however, are just a matter of hot and ground—a center conductor and an outer shield separated by a foam dielectric. In all cases, the center conductor, or "stinger", extends past the aluminum shield by two or three inches.

The cable is cut to length using either a hacksaw or a pair of cutters. On underground or flooded cable, the next step is to peel back the outer plastic shield. A tubing cutter is used to lightly score the aluminum outer shield all the way around. The location of the scoring determines the length of the stinger, so make your mark accordingly.

Grasp the end of the aluminum with a channel-lock or pair of pliers. A side to side bend will snap the shield loose. Pull straight up and slide it right off the foam dielectric. If it is difficult to pull the shield off, you may have scored too deeply with the tubing cutter. When installing underground cable, take a rag and some solvent, such as paint thinner, and wipe down the outside of the aluminum to remove any sticky goo so that your connector makes a good ground connection.

Your next move depends on the style of connector used. Some connectors are ready to go right on, but these are considered "B Grade" because they do not offer the degree of shielding that helps to insure no signal leakage.

Grade A connectors have a sleeve that slips down inside the aluminum shield, effectively enclosing the center conductor. To accomplish this, remove the foam dielectric approximately an inch from inside the shield. This is done with a "coring" tool. The center conductor goes up through the middle, while the tool is twisted like a cork screw. The foam comes out and the connector is ready to go on.

The most common type of hardline connector in use is called an "Entry" connector. It joins the hardline cable to just about any and all pieces of hardware you will ever use. This connector comes in two pieces. The bottom piece first slides over the cable. A wrench is used to thread the top half into the body of your hardware. The two halves are then threaded together. As they are tightened, a snug fit is made onto the cable. Grooves in the connector bite into the cable's outer sheathing, ensuring a good ground connection. Don't over tighten; you could kink or damage the hardline cable.

A big piece of heat shrink tubing over the whole splice helps to seal out moisture.

Use an ohm meter (there should be no voltage on the line) to check continuity and for shorts. If you make the stinger too long, it can come in contact with the body of the connector or tap, casuing a direct short. It is always a good idea to check the cable for shorts before you apply power to the line.

The Drop

The run from the tap to the house is known as a "drop". Standard RG6 or RG59 coaxial cable is used for this purpose. If the drop runs through the air, the coax will have a "messenger" steel cable bonded to it which supports the cable's weight at each end. In underground systems, the coaxial cable comes out of the ground just outside of each house or building served by the system. Use a "flooded" cable, which has a goo between the shield and the dielectric to keep out moisture.

At the house, you'll need a ground block connected to a ground rod pounded several feet into the ground. The ground block has a double

female F connector with a screw terminal for a ground connection. This provides a measure of protection from lightning and power surges.

Program Delivery Options

Many systems will offer multiple packages or "tiers" of program channels: basic services, such as off-air channels, satellite Superstations, news and sports services; and premium movie channels. Although all subscribers will want access to the basic services, not everyone will be willing to pay the additional subscription cost for a premium movie channel or a pay per view event.

Since the premium movie channels are multiplexed onto the cable along with everything else, the system operator must have a way to block or "trap " these services before they enter the homes of subscribers which are not paying for the additional services. A trap is a specialized filter that notches out the unwanted channel or channels. It is installed in the pedestal on the output of the tap, in series with the coaxial cable feeding the customer's TV set.

One technique is to use a single trap to feed the signals into multiple output splitters. All houses or apartments subscribing to a particular tier are connected to a common splitter. These traps require more signal output from the tap to compensate for the extra splitter loss.

Still another method is the reverse trap. Here a special device at the head end places an interfering carrier on the video signal. At the home, the audio is present, but the video appears to be scrambled. A trap is installed in the pedestal which strips off the carrier and returns the video to normal.

One of the most rapidly growing areas in private cable distribution is Pay Per View, the ability to sell programs on a event-by-event or movie-by-movie basis. Until recently, the cost of this technology was too expensive for any except the largest cable operators. With a growing demand to push development, new cable distribution systems are being developed which use inexpensive personal computers equipped with specialized software which control special cable converter boxes. This area is so new that the best advice may be to find a reliable hardware supplier who has confidence in—and will back up—a system that can satisfy your customer's particular needs. This supplier can be a great source of assistance, helping to select the right components for successful completion of the project.

Installing Hardline Splitters

One of the keys to planning an effective cable distribution system is to carefully determine where to install the hardline splitters which divide the signal—allowing you to take the signal down different roads or directions—as well as where to insert any amplifiers or "line extenders" to boost the signal back up to acceptable performance values. Your line extender will increase the signal by about 25 dB. Whenever the signal level drops down to about 20 dB, it is time to add a line extender. That returns you to a healthy 45 dB, and you are ready to continue. The dB or signal strength meter is an essential tool for knowing exactly how much signal power you need at any point in the system.

The system designer usually figures this all out on paper in advance of construction, factoring in variables such as the signal loss on the cable per hundred feet, loss due to splitting the signal for each feeder line, and the number of TV sets involved. It is possible to determine the proper values as you go along, keeping track of the signal level, and adding a line extender whenever necessary to maintain acceptable performance levels. But first, get your calculator out, arm yourself with a few statistics, and get a rough idea of what materials you will need. Figure on a little signal overkill when working out the estimate for larger installations.

Keep in mind that channels higher in frequency will show more loss than low band channels like VHF 2 - 6. In a system that uses midband, channel 13 will show the most loss. Move up into superband, and the loss is even greater. For this reason, the dB levels are often "tilted" in the direction of the highest channels. When the power output is set at each amplifier in the system, the high frequency channel may be 5 dB or more stronger than channel 2. With cable loss, by the time the broadband signal

reaches the next amplifier, the tilt will have equalized. The output of each additional amplifier in the distribution system is tilted throughout the system to insure that channel signal levels are equal at all delivery points.

Other Uses For the Hardline Splitter

One of the most important pieces of hardware in a private cable system is the two-way splitter. The splitter does the obvious job of dividing the main signal so that it can be sent in two different directions. The hardline splitter, however, has some other potential uses as well. The splitter also can serve as a convenient housing for other electrical circuits that are needed to make the distribution system perform correctly.

As a Power Inserter. The hardline splitter can be used at the head end as a "power inserter" to place AC voltage onto the cable distribution system. This simple but vital function is found in all systems utilizing AC line powered amplifers.

Installation is fairly straightforward. Each port on the inserter is clearly marked. On one side is the input for the signal from the equipment rack, coming from the output of the combiner. You can count on it nearly always leaving the headend rack as a piece of RG-59 or RG-6 cable. At the other input, is the connection for the AC. It also comes to the inserter as a cable from the power supply, either on a coaxial cable or a piece of hardline.

First, the appropriate style connectors are installed on the inserter, a hardline entry connector. With the two input signals connected, the output of the inserter is now a multiplexed signal containing all of the many channels from the combiner, plus the AC voltage.

As a Splitter. Distribution systems consist of a main trunk line, which at times is divided or split, routing the signal down separate paths. If used as a pure splitter, the signal is divided into two equal halves. But more often, the trunk cable serves as the primary line with other shorter legs tapping off to feed smaller groups of TV sets. Therefore, only a small portion of the signal is removed from the main trunk, while the balance continues on down the line to the next distribution leg or amplifier. The tap off port will be labeled in reference to the amount of signal siphoned away, something like 8 or 12 dB. The tap also can be used to remove an unwanted amount of signal before reaching a distribution amplifier or line extender so that you do not over drive the amplifier and create distortion.

As a Way to Control Voltage. In many cases, the shorter distribution legs will not have any amplifiers. The signal runs down the feeder line until all TV sets on that leg have been served. Since this feeder line has no need for AC power, a splitter equipped with a removable internal fuse can be used to remove AC power from that portion of the line, while allowing the RF signal to pass through.

This can be helpful for a number of reasons:

Power consumption is reduced by not sending electricity down a leg of cable which has no need for it. Although the amount of electrical consumption may be small, if several lines are involved, this can add up. Also remember that this unnecessary AC consumption will take place 24 hours a day, every day throughout each year.

Another reason for using a splitter with a removable internal fuse is for added convenience during servicing. If there is a bad amplifier which needs to be replaced, or even more serious, a damaged cable which must be spliced, the repair task will be much easier if the AC is removed from the affected feeder line before the work begins. If the AC power is turned off at the headend, voltage will be removed from the entire system, disrupting everyone's service. It is much better to remove power only from the feeder leg which needs servicing, leaving all other legs operational.

As might be expected, the internal fuses also serve to protect hardware and equipment. Should a power surge enter the line, due to an accidental short or a nearby lightning strike, the fuse will blow, stopping the power surge dead in its tracks.

Distribution Links

In today's urban environment, developers often find themselves needing to link properties or buildings separated by great distances or

apparently insurmountable obstacles. A popular although expensive solution can be a microwave or even laser link. The transmit and receiving antennas must be kept within a line of sight and accurately aligned. When a direct cable connection is impossible, either due to a natural or man-made obstruction, or a legal "right of way", the wireless route can be the perfect solution.

Installation

For the cable operator running overhead lines, the installation process is fairly straightforward. The trunk cable comes in from one end and the two (or even three) outputs exit from the other.

However, private cable installations almost always have underground distribution systems. All cables—the input as well as the outputs—come from the same direction, straight out of the ground. The input and outputs on the splitter are on opposite ends. One must make a 180 degree turn to reach the ports on top of the splitter, all within the confines of the pedestal. Even the slightest bend in hardline cable, if not done very carefully, can cause a kink. At worst, the aluminum outer shield collapses, shorting out the center conductor. Or a kink can create a "ripple" in the signal which can turn up on TV sets as ghosting.

To accomplish an 180-degree turn in a space of only a few inches, special "right angle" connectors must be used. They may vary slightly in the length of their center conductor. Two of them must be used together (90 + 90 = 180) to complete the turn around.

Let's look at an example. Assuming the cable lengths exiting the ground permit, the most logical method of installation is to have both outputs enter the splitter directly from the bottom, a straight shot. This leaves only one cable—the input—that needs to go through the turn. The cable comes up, enters a right angle connector,with a second right angle connector used to complete the curve.

The right angle connector is female on one end and male on the other. The cable is stripped back leaving a "stinger" of a couple of inches long. An entry connector is attached to the cable before attaching it to the female side of the right angle. The output end of the connecter has its own stinger, which is fed into the next right angle connector, into the splitter, amplifier, or whatever is next.

A secure and positive connection is made with the stinger by means of a set screw. The screw is accessed through the removal of a small cap, and is tightened down with a common flathead screw-driver.

Installation of the stinger in the right angle connector requires some extra special attention. Because the connector makes such an abrupt turn, the length of the stinger must be cut to the proper length so that it does not come in contact with the outer case or "ground" of the second connector. Once the connector is installed, check it with an ohm meter, placing one probe on the set screw, and the other against the outer case. If it shows a short, take it back apart, shorten the center conductor, and reassemble. It should be just long enough to slip in past the set screw by about a quarter of an inch. Cut it too short and you risk the chance of making a poor connection. Fluctuating temperatures can cause electrical contacts to separate when the connection is marginal.

In some cases, it may not be necessary to make a full 180-degree turn. Each splitter port has two points of entry, 90 degrees apart from each other. Through one opening is the entry from the stinger. The 90 degree counterpart is where the set screw resides. These can be alternated, as the screw can be pivoted, placing the set screw at the stinger entry position and vice versa. The stinger entry is now on the side, so only one right angle connector is needed to complete the turn. The ability to alternate or choose between a side or end point of entry can be found on most hardline equipment, including amplifiers and taps. Basically, it increases your installation options, and can be helpful when installing many pieces of equipment within the limited confines of a pedestal.

Familiarity with the hardline splitter is essential for the installation of any major distribution system. Having a better understanding of the various types and uses will help you during the design stage and when ordering parts.

Chapter 12

The Effects of Solar Outages and Rain Fade on Satellite TVRO Reception

All life depends on the Sun. Just as in life itself, satellites require the Sun's power for their continued existence. What many casual observers may not know is that the fiery orb at the center of our solar system also can wreak havoc on space communications. Solar outages, eclipses, and sunspot activity can disrupt our reception of satellite TV programming. Solar outages and eclipses occur at predictable and regular intervals. What's more all of the above-mentioned solar phenomena are only in effect for very short periods of time.

Solar Outages

During the days surrounding the Spring and Autumn equinoxes—the two times each year when the Sun crosses the equator and day and night are of equal length—the Sun will move through an arc in the sky that is directly behind each successsive geostationary satellite. When this phenomenon occurs, normal satellite communications will be disrupted.

The noise temperature of the Sun, which is over 25,000 degrees Kelvin, dramatically raises the noise temperature of the receiving satellite

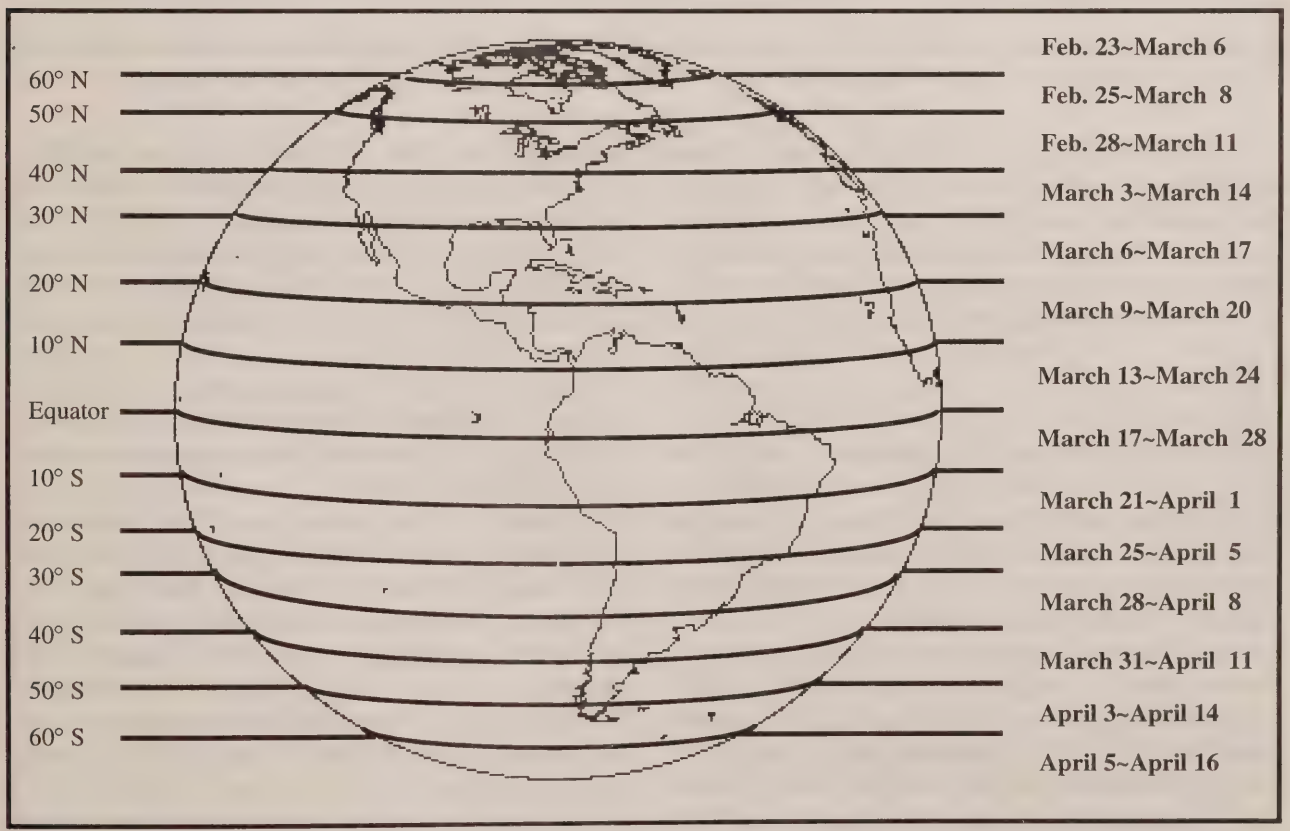


Fig. 12-1. Spring Solar Outage Periods for North and South America

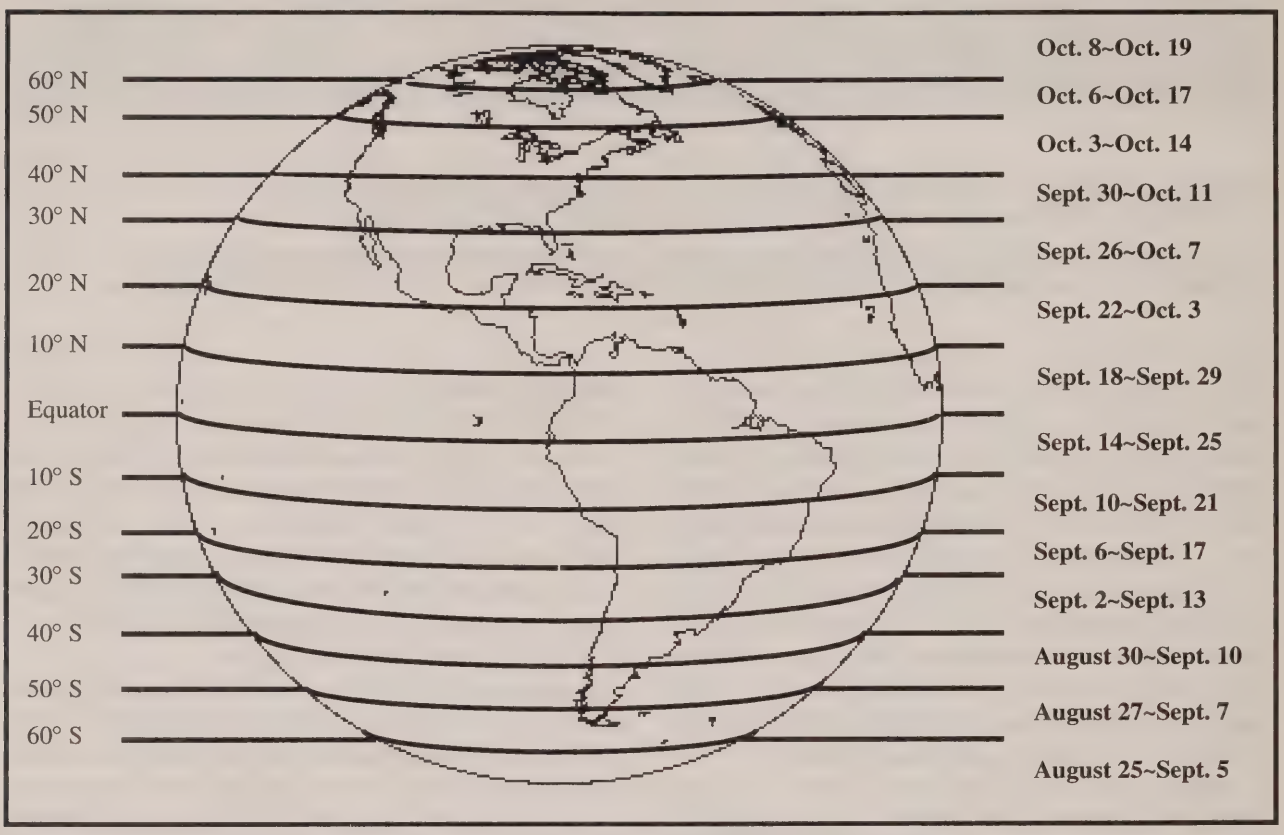


Fig. 12-2. Autumn Solar Outage Periods for North and South America

antenna, causing a partial or complete obliteration of the satellite signal. This disruption can last anywhere from thirty seconds to eighteen minutes. When an outage occurs involving a satellite that is being viewed at the time, the picture will be invaded by impulse noise or "sparklies." The intensity of the interference will rise rapidly until the incoming signal is totally lost in the solar noise.

The solar outages will occur on a daily basis for a period of a week or more around the time of the equinoxes. The exact time and length of each daily outage will vary, depending upon the latitudinal position of the earth station with respect to the Earth's equator.

Solar outages have been known to damage earth station equipment. I learned of this fact the hard way. Many years ago, a satellite manufacturer delivered an unpainted spun aluminum antenna for my evaluation. The installation of the antenna happened to coincide with the Autumn equinox. One afternoon, as I walked through the antenna "farm" outside my office, I noticed that smoke was rising from behind the unpainted antenna's feedhorn. Earlier that afternoon, the Sun's energy had fallen directly into the prime focus area of the dish. The antenna reacted like a high-powered lens and turned my new antenna into a super solar oven. An inspection of the damage revealed that the coaxial cable and the servo motor casing on the back of the feedhorn had been transformed into melted blobs of plastic.

If moisture has gotten past the seals and ingressed into the LNB, the concentrated sunlight can vaporize the condensation inside the amplifier and cause the device to literally explode like a pressure cooker run amok. In less extreme instances, the pressure caused by the rapid heating of condensation inside the LNB can destroy the amplifier's water-proofing seals, leading to later damage from weather.

Unpainted metal parabolic antennas, or even those coated with a highly reflective painted

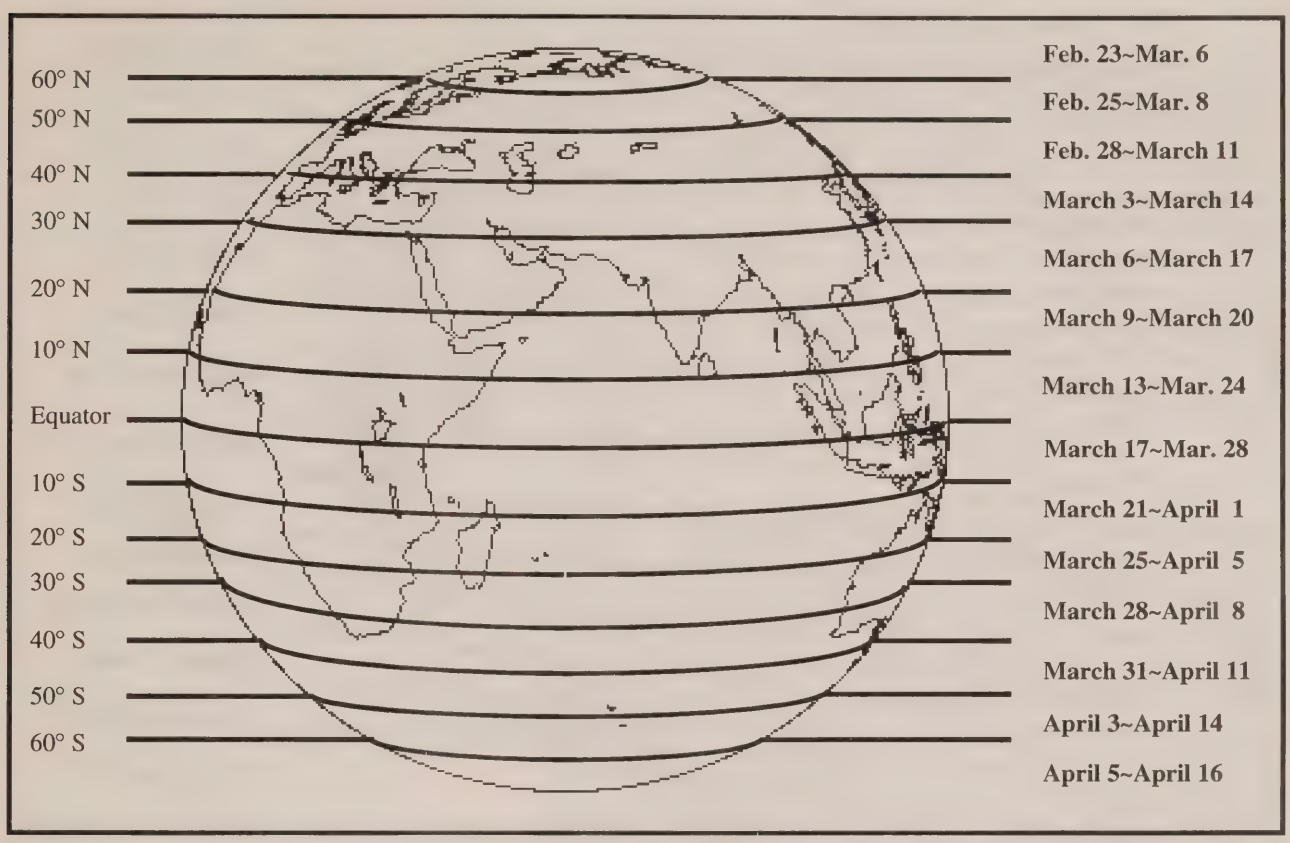


Fig. 12-3. Spring Solar Outage Periods for Europe, Asia, Africa & the Middle East

surface, can rapidly concentrate sunlight falling into the prime focus area until temperatures several thousands of degrees are achieved. The best solution to this problem is to resurface the antenna with a non-reflective paint that will disperse rather than concentrate the Sun's rays.

A Dependence on Solar Energy

All communications satellites have solar arrays that convert sunlight into electricity. These photovoltaic arrays are the primary source of power for the satellite. The arrays also charge the satellite's battery system so that power will be available during solar eclipses or whenever the instantaneous power requirements of the spacecraft are exceeded.

Spin-stabilized satellites such as Galaxy I or Westar V have most of their outer surfaces covered in solar cells. The regular spin rate of the spacecraft's main body causes these cells to be illuminated continuously by sunlight. Three-axis stabilized satellites such as SPACENET III or Satcom C-1 carry solar wings covered with thousands of solar cells. Each international INTELSAT satellite, for example, has 17,568 solar cells that together can produce 1,742 watts of power at the beginning of each spacecraft's mission lifetime.

Solar Eclipses

Like solar outages, solar eclipses also take place during the periods surrounding the equinoxes. A solar eclipse occurs whenever a geostationary satellite falls within the Earth's shadow. During the period in which the Earth shadows the satellite's solar array from the Sun, the spacecraft's on-board storage batteries provide the required power. The batteries discharge during the eclipse periods and then recharge during periods of illumination. The length of the solar eclipse ranges from about 10 to 70 minutes in duration.

Legendary science fiction writer and math-

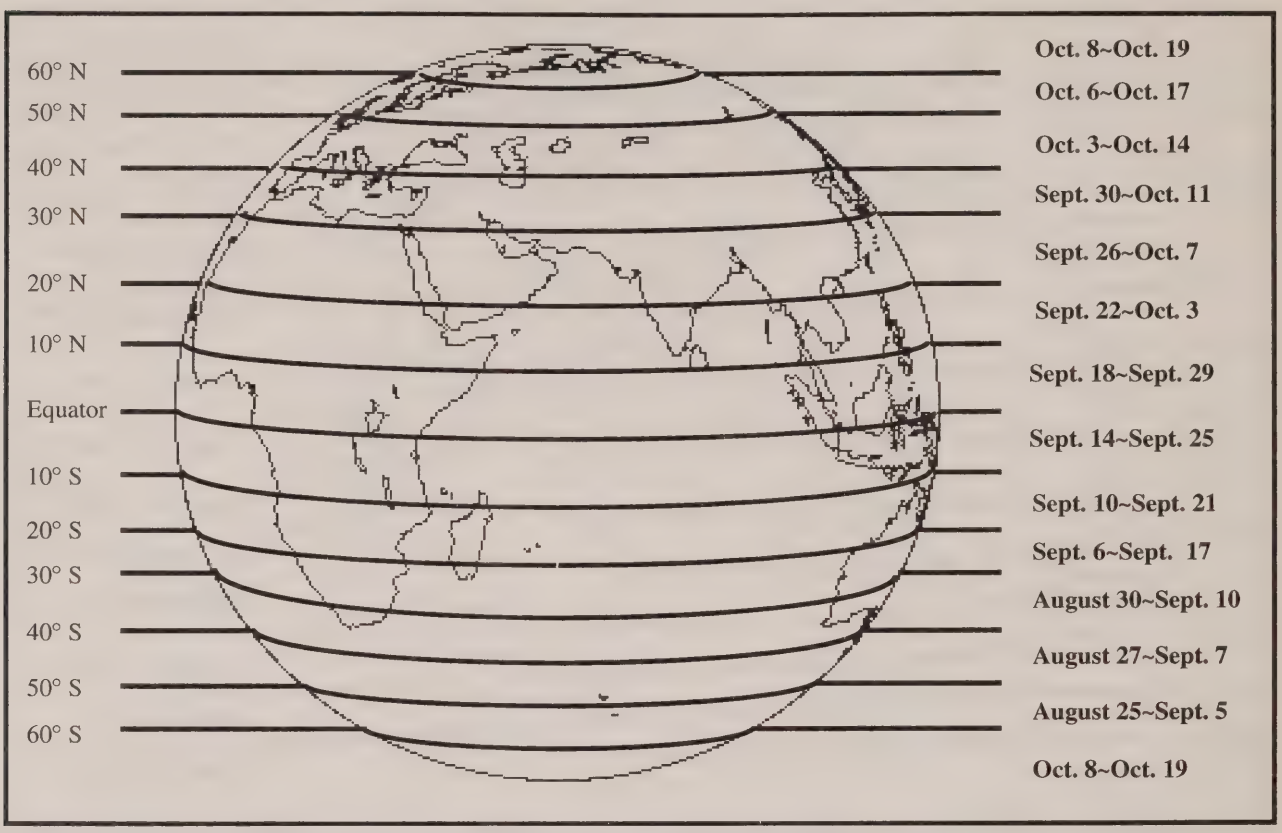


Fig. 12-4. Autumn Solar Outage Periods for Europe, Asia, Africa & the Middle East

ematician Arthur C. Clarke was the first individual to mention the potential effects of solar eclipses on satellite communications. In his visonary article entitled "Extra Terrestrial Relays (October, 1945 issue of *Wireless World* magazine) he wrote that each satellite "would be in continuous sunlight except for some weeks around the equinoxes, when it would enter the Earth's shadow for a few minutes...."

Every day, as the satellite makes its revolution above the Earth's equator, "it would cut more deeply into the shadow, undergoing its period of maximum eclipse on March 21st," when the satellite would be in total darkness for a period lasting about one hour and 9 minutes.

"From then onward, the period of the eclipse would shorten, and after April 11th the station would be in continuous sunlight again until the same thing happened six months later at the Autumn equinoxes, between September 12th and October 14th."

Since the longest period of the eclipse is just over an hour, there usually is no difficulty in powering a satellite from energy stored in the spacecraft's batteries. However, as satellites approach the end of their mission lifetimes, the power generated by their photovoltaic arrays and the ability of the on-board batteries to store electrical energy dramatically decreases. During the solar eclipse periods, the operators of older satellites may be forced to shut down some of the satellite's transponders in order to conserve limited energy supplies.

Sun Spots and Faraday Rotation

Violent whirlpools of ultraviolet radiation located on the surface of the Sun electrically charge the upper layers of the Earth's atmosphere, called the *ionosphere.* The ionosphere may be located anywhere from 25 to 250 miles above the Earth. Its height at any given moment depends on the season, the time of day, the temperature of the Earth, and the intensity of the Sun.

Sunspot activity has been monitored and recorded for over 200 years. Scientists have

learned that the number of sunspots goes up and down in an eleven-year cycle. The more sunspots there are, the more highly charged the Earth's ionosphere.

Solar storms reached an eleven-year peak in February of 1990. Sunspot activity should slowly decrease from this peak until reaching its lowest point in the 1995 to 1996 time frame. The next peak in solar activity will occur in 2001.

Because satellite signals must pass through the ionosphere on their way from the satellite to receiving stations down on the ground, sunspots have the potential to disrupt satellite reception without warning.

An unwanted propagation effect called "Faraday Rotation," can occur whenever satellite signals pass through the highly charged layers of the Earth's ionosphere. Faraday Rotation actually can rotate or "twist" linearly-polarized (horizontal and vertical) microwave signals so that the polarization vector is altered substantially. Circularly polarized signals are not nearly as susceptible to this effect.

Satellites reuse the available frequency spectrum twice by simultaneously sending overlapping TV channels with the polarization switching from horizontal to vertical every other channel. Normally when the receiver is set to pick up a vertically polarized channel, the horizontal channel cannot be seen. This is because the orthogonally polarized signals travel together, but at right angles to each other

If the satellite receiver's skew control (in linearly polarized systems) inadvertently is set somewhere between the peak adjustments for horizontal and vertical, however, it is possible to view two channels at once, an unsatisfying viewing experience at best. Likewise, whenever Faraday Rotation occurs, a satellite TV receiver looking for horizontally or vertically polarized signals will have difficulty in distinguishing between the two polarities. However, this rotation usually can be compensated for by temporarily adusting the satellite receiver's skew control to repeak the signal..

Predicting Solar Outages by Jim Roberts

The Sun has an apparent angular diameter of about one degree, when viewed from Earth, and moves its diameter in transit about every four minutes. A satellite antenna with a one-degree focal resolution will, on the worst day, experience an outage for about seven minutes as the Sun moves into, through, and out of its focus. A dish with a two-degree focal resolution will experience an outage for about fifteen minutes. The one-degree antenna will only experience outages for about four days before, and after, the worst day, while the two-degree antenna will catch them for more than a week on each side of the worst day.

The worst day in the Northern Hemisphere will occur before the Spring Equinox and after

DATES OF SPRING OCCURRENCE
(± 2 DAYS)

Latitude	21°	27°	30°	33°	37°	40°	43°	47°	50°	53°	63°
North of Equator:	3/13	3/10	3/9	3/8	3/7	3/6	3/5	3/4	3/3	3/2	2/28
South of Equator:	3/28	4/1	4/2	4/3	4/4	4/5	4/6	4/7	4/8	4/9	4/11

DATES OF AUTUMN PEAK OCCURRENCE
(± 2 DAYS)

Latitude:	21	27	30	33	37	40	43	47	50	53	63
North of Equator:	10/1	10/4	10/5	10/6	10/7	10/8	10/9	10/10	10/11		10/12 10/14
South of Equator:	9/14	9/11	9/10	9/9	9/8	9/7	9/6	9/5	9/4	9/3	9/1

the Autumn Equinox by the below table's "day shift." The Equinox generally fall around the 20th of September and March. They are often noted in calendars by such charming titles as "Last Day of Summer" and "First Day of Spring." For all practical purposes, the worst day is the same one for all of the available satellites.

The peak times, on your watch, of the occurrences are the collective result of: the seasonal shift in the Earth's speed, your exact time zone, Daylight Savings Time consideration, and the satellite's longitudinal separation from the site location.

The peak times are basically the same (for each satellite) for the lesser/shorter outages on the days before and after the Peak Day, as they are on that worst day. The following Table of Values and text can be used to calculate the approximate times for international locations.

In the Autumn, the Earth is further from the Sun and moving more slowly. The seasonal correction column in the above Table of Values is the number of minutes to be subtracted, at your longitude, to your Local Time, for that effect. If you are at 40 degrees in latitude (you subtract 12 minutes), your Fall Solar Noon is thus 11:48.

The site longitude determines your True Time Zone, in increments of 1 hour for each 15 degrees (works out to a nice even 4 minutes per degree) from good old Greenwich Observatory, where Earth time starts. Figure site longitude's difference from the nearest even multiple of 15 degree longitudinal steps. If you are located at 101 degrees West Longitude, your nearest even 15 multiple is 105 (7 x 15 = 105), and you are four degrees less than that, so your True Time Zone is 16 minutes ahead of Local Time Zone (4 degrees at 4 minutes per degree). Your Autumn True Solar Noon (11:48, less this 16 minutes time zone correction) is 11:32. If your location is observing Daylight Savings Time, you also must add a full hour, i. e., 11:32 becomes your very own Autumn, True, Daylight Savings, Solar Noon of 12:32.

This hard won value is the reference against which to figure the lead/lag time for the Sun's alignment (before Noon) behind the site location's Easterly Birds, and (after Noon) behind the available Westerly birds.

Each satellite's lead, or lag, time for the Sun's being behind it from the system's view is the number of degrees difference between the satellite and the site longitude, multiplied by the Table of Values's "Satellite Lead/Lag" rate (in minutes per degree) for the site latitude. If a satellite is 30 degrees East of the earth station site (i. e. has 30 degrees less West Longitude), and the site is at 40 degrees North Latitude, the Sun will be peaked behind that satellite at 2 hours and 13.5 minutes (30 x 4.45 = 133.5 minutes) earlier than the Sun reaches Solar Noon for your site. Given a Solar Noon Time of 12:32, less 2 hours and 13.5 minutes, rounds off to 10:18, or the time of morning at which the Sun is at the peak of its passage behind the satellite which is 30 degrees East of the earth station site.

Remember, depending on the antenna's focal efficiency, the effects of the Sun's presence will have begun to be felt several minutes before, and will continue several minutes after, the peaks that take place on the worst day.The effects will occur for shorter periods, centering on those same times of day (with each satellite orbital position having its own unique time) for several days before and after the worst day.

A good 12 foot dish should suffer only three days before, and after, the peak and for periods of less than nine minutes. Smaller, and/or misshaped dishes may suffer as much as twice that long (both in the days before and after, and in the minutes of duration).

Fig. 12-5. Values for International Locations

LATITUDE	DAY SHIFT[1]	SEASONAL CORRECTION[2]	SATELLITE LEAD/LAG[3]
10	4 days	9 minutes	4.59 min/deg
20	8 days	10 minutes	4.56 min/deg
30	12 days	11 minutes	4.51 min/deg
40	15 days	12 minutes	4.45 min/deg
50	18 days	13 minutes	4.37 min/deg
60	20 days	14 minutes	4.28 min/deg

(1) Ahead of Spring Equinox, behind Autumn Equinox for Northern Hemisphere
(reverse for Southern Hemisphere).
(2) Add in Spring, Subtract in Autumn.
(3) Add for Satellites West of site location, subtract for those East of site location.

Rain Outages

Signal attenuation—weakening due to rainfall, snow or even sand storms—should be taken into account when designing any Ku-band satellite earth station. Raindrops can scatter or absorb satellite signals as the spherical wavefront of the transmitted microwave energy radiates earthward through the various atmospheric layers. As the wavelength of the transmitted microwave signal approaches the size of the raindrop, signal attenuation becomes more severe. Although atmospheric losses are negligible at frequencies below 7.5 GHz, higher-frequency signals can sometimes suffer significant losses; torrential downpours can produce large rain droplets that can markedly weaken Ku-band (11/12 GHz) satellite signals. In Asia and the Pacific Rim and elsewhere, Ku-band satellite signal reception can be drastically reduced during downpours. The curves presented in the chart on the following page show the relative rain rates for various U.S. and European regions. For example, a rate of 5.6 millimeters per hour (mm/hr) is exceeded 0.1 percent of the time in Region B, or 8.8 hours in a year. In region E, the worst-case rainy area in the Southeastern U.S., the rain rate of 35.4 millimeters per hour is exceeded during the same interval. In addition to increasing uplink and downlink losses, rainfall also can raise the noise figure of the system, since the rain itself has a noise temperature of 290 degrees Kelvin—substantially higher than the background temperature of clear sky or space.

To counteract the effects of heavy rainfall, a Ku-band satellite receiving system should be designed to produce a margin of several dB above receiver threshold to maintain good satellite reception even under worst-case conditions. The best way to achieve a margin of several dB is to select a larger antenna. Selecting a lower noise temperature LNB is not an effective solution, since the rain-filled sky generates a higher-than-normal noise temperature that will counteract any noise gains made within the electronic circuitry of the earth station.

To ensure 99.9 percent availability, we recommend the following margin levels for commercial satellite operators at locations in or near the following cities:

Miami	Rain Zone E	+10 dB
Rome	Rain Zone D	+6.3 dB
Amsterdam	Rain Zone C	+3.3 dB
Casablanca	Rain Zone F	+2.0 dB
London	Rain Zone B	+3.7 dB

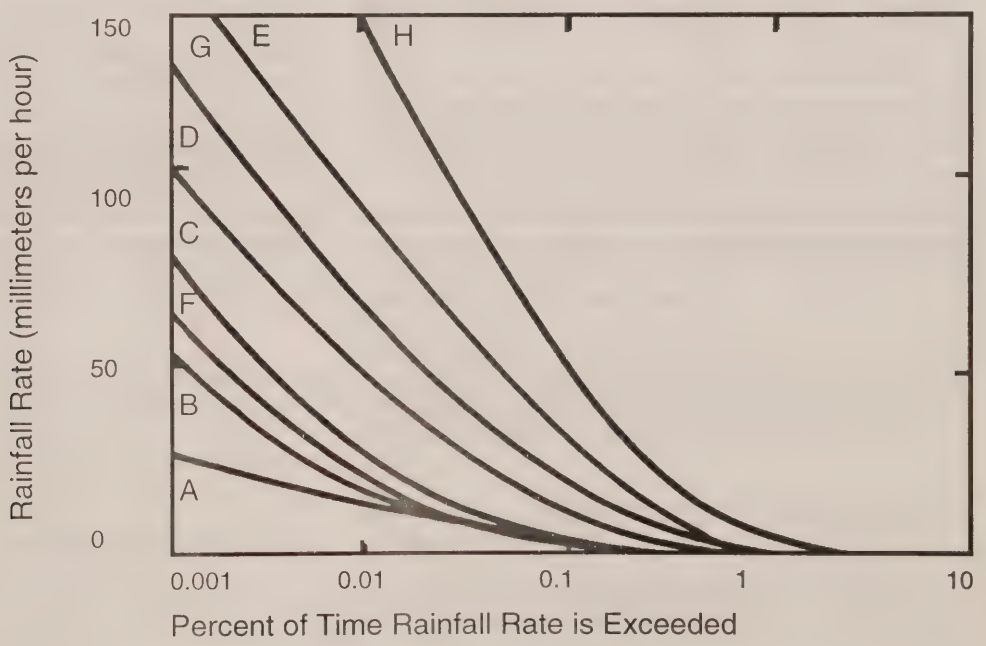
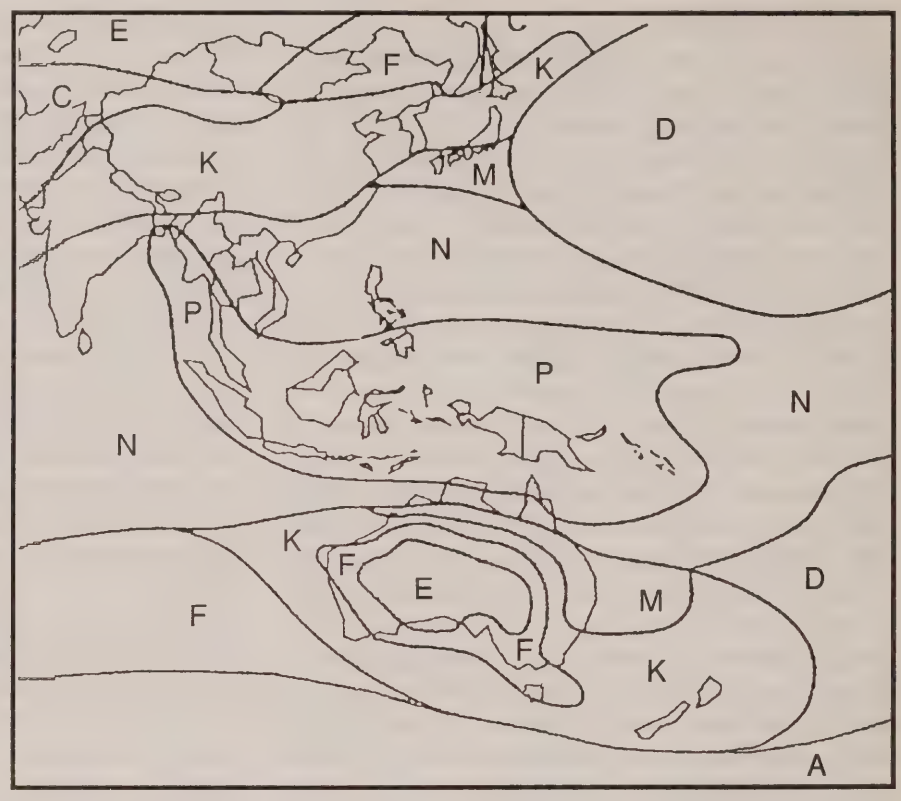


Fig. 12-6. Relative Rain Rate Chart

Fig. 12-7. Asia/Pacific Rain Rate Zones

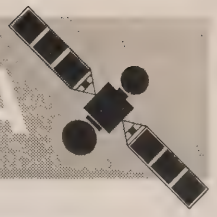


A = 8mm/hr
C = 15mm/hr
D = 19mm/hr
E = 22mm/hr
F = 28mm/hr
K = 42mm/hr
M = 63mm/hr
N = 98mm/hr
P = 145mm/hr

Of course, tropical and sub-tropical areas around the world receive considerably more rainfall than the Southeastern United States, so the margin-above-threshold in dB is even higher for these regions. Conversely, semi-arid climates may require even less than the margin recommended for earth stations in San Diego, CA. However, desert locations have to attend to another type of attenuation altogether: massive sand storms can blow so many particulates in the air that reception is interrupted.

Although commercial satellite terminal operators cannot tolerate any interruption in service, some private earth station owners should be able to accept a limited amount of rain outages and will purchase a lower-cost system that delivers a lower margin signal, or perhaps no margin at all. For example, if one were content with achieving a 99-percent signal availability rate, the video at many site locations within the United States or Europe would be driven below receiver threshold and into sparklies on an average of only 3.65 days a year, with a significant portion of that time occurring during work hours or at other times when viewers are not watching their TV sets.

Appendix A



A Glossary of Satellite Related Terminology

ABC (1)—American Broadcasting Company. Major U.S. network.

ABC (2)—Australian Broadcasting Corporation. Government-run organization which relays via satellite east- and west-coast editions of ABC network television programming to locations throughout the Australian continent.

ABU—Asia-Pacific Broadcasting Union.

ACATS—The U.S. Advisory Committee on Advanced Television.

ACI—Adjacent-Channel Interference.

A/D—Analog/Digital (Conversion). See ADC.

ADC—Analog to Digital Conversion. Process of sampling and coding an analog quantity or signal to produce a digital representation.

ADM—Adaptive Delta Modulation. Digital coding method employed by Dolby Labs' satellite TV audio system, to be used (via B-MAC) by Australia's HACBSS.

AFRTS—American Forces Radio and Television Service (USA). TV news program service distributed world-wide via INTELSAT.

AITV—Agence d'Images (French TV news agency). Handles news feeds via INTELSAT and Telecom F1.

AKM—Apogee-Kick Motor (also ABM, Apogee-Boost motor). Rocket motor fired at highest point of GTO, to circularize orbit and inject satellite into GEO.

AM—Amplitude Modulation. The baseband signal is caused to vary the frequency of the carrier wave.

A-MAC—see MAC.

Analog—A signal waveform that can be continuously variable in intensity and/or frequency. (Also see digital).

ANSCS—Australian National Satellite Communications System. (Also see AUSSAT.)

Antenne-2—French TV's second terrestrial channel, partner in TV5.

AOR—Atlantic Ocean Region (as defined by INTELSAT).

AOS—Acquisition of Signal.

Aperture—The effective diameter of a parabolic antenna which intercepts the incoming microwave signal.

Apogee—Highest point (maximum altitude) of a geocentric orbit. (Also see Perigee.)

ARABSAT—Arab Satellite Communications Organization. F1 and F2 satellites operate from 19 and 26 degrees East Longitude.

Architecture—An arrangement for signal processing and transmission.

ARD—Co-ordinating body for West German TV's terrestrial networks.

ARO—Audio Receive Only.

Ariane—Family of Europeanlaunch vehicles. (Also see CSG.)

ASBU—Arab States Broadcasting Union.

ASCII—American Standard Code for Information Interchange. Text coding used by computer systems.

ASEAN—Association of South-East Asian Nations includes Malaysia, Thailand, the Philippines, SIngapore, Indonesia and the Sultanate of Brunei. ASEAN countries share in the use of the Palapa satellite system.

ASETA—Associacion de Empressas Estatales de Telecommunicaciones del os Paises del Pacto Subregional Andino. The Association of State Telecommunications Agencies for the Andean Region.

Aspect Ratio—A numerical expression of the width versus the height of a TV screen's display area. Standard NTSC, PAL and SECAM TV sets have an aspect ratio of 4:3 while future HDTV screens will provide a 16:9 aspect ratio.

ATC—Argentina Televisora Color. Buenos Aires station distributed by INTELSAT.

ATS—Applications Technology Satellite. Early series of NASA experimental satellites.

Attenuation—The measure of signal loss in a transmission medium or component usually expressed in deciBels (dBs) or deciBels per unit length (kilometer or mile). Satellite transmissions at the higher end of the microwave frequency bands are more susceptible to attenuation caused by heavy rains.

Attitude control—The orientation of the satellite in relationship to the Earth and the Sun.

Axial Ratio—A measure of circularity of polarization, related to a CP antenna's XPD.
AZ—the azimuth angle (see azimuth).

Azimuth—Angle between antenna beam and meridian plane (measured in horizontal plane).

A2F—Antenne-Deux France. (Also see Antenne-2).

Backfire—A dual reflector feed system of undefined geometry.

Backhaul—A terrestrial link connecting an earth station to its local switching center or population center.

Baikonur—The Soviet Kosmodrome at Tyuratam.

Band—A unit for designating a specific frequency or range of frequencies in the electromagnetic spectrum.

Bandwidth—The range of frequencies occupied by a signal, or passed by a transmission channel. Services requiring a bandwidth greater than 20 kHz, such as television transmissions, are known as "broadband." Those requiring less capacity, such as telephone transmissions, are known as "narrowband."

Baseband—The band of frequencies containing the information, prior to modulation (and subsequent to demodulation).

Baud—Unit of data transmission rate, based on the number of signal elements or symbols transmitted per second.

Baudot—The international teletype code.

BB—Baseband.

BBC—British Broadcasting Corporation.

BCD—Binary coded decimal.

BDC—Block Downconverter or Block Downconversion.

Beacon—Low-power carrier generated by an auxiliary transmitter. May be unmodulated for propagation tests or tracking, or modulated with telemetry or tracking data.

Beam Hopping—The capability of satellites to shift their beam rapidly—in a matter of milliseconds—so that data can be sequentially processed from multiple earth stations.

Beamwidth—The acceptance angle of an antenna, usually measured between half-power (3 dB) points.

Bearer Circuit—One circuit that can be divided by circuit multiplication equipment to carry more than one derived circuit.

BER (or b.e.r.)—Bit Error Rate. Accuracy of digital demodulation or decoding. Analogous to SNR, but in digital transmission.

BFBS—British Forces Broadcasting Service.

BG—Board of Governors (INTELSAT). Denotes an INTELSAT specification.

BIS—British Interplanetary Society.

Bit—A binary digit. Smallest possible unit of digital transmission.

Bit Rate—Speed of digital transmission, measured in bits per second (bits/s or b/s), or multiples of thousands or millions (Kbits/s or kb/s, Mbits/s or Mb/s).

Blanking Interval—The portion of the video signal which occurs between succeeding picture frames. The blanking interval contains syncronizing information and, in some cases, teletext signals.

Blanking Level—The level of a composite video signal that separates the spectra containing video information from the spectra containing the synchronizing information.

Block Downconversion—The use of a fixed-frequency first local oscillator, to downconvert an entire satellite band to a lower intermediate frequency for subsequent tuning and demodulation.

B-MAC—see MAC.

BO—Backoff (of non-linear system, from saturation). In a satellite transponder, may be qualified as input backoff or output backoff.

BOL—Beginning of Life (of a transponder or satellite).

Boresight—Axis of symmetry of a paraboloid. (Loosely: beam center).

BPF—Band-Pass Filter.

BPSK—Binary Phase-Shift Keying. (Also see PSK.)

BPU—Baseband processor unit.

Brasilsat—Brazilian domestic satellite system. (Also see SBTS.)

BrightStar—International TV news and videoconferencing agency.

BS—Broadcasting Satellite (Japan).

BSE "Yuri" (Lily)—Broadcasting Satellite for Experimental Purposes. Precursor of Japan's BS.

BSS—Broadcasting-Satellite Service. (Also see FSS.)

b/s—bits per second.

BT—British Telecom (UK).

BTI—British Telecom International.

Byte—A digital "word," usually consisting of eight bits.

Canal Plus—French TV's fourth terrestrial channel.

Carrier—The radio frequency wave that is modulated by the baseband information signal.

Cassegrain—Dual-reflector antenna geometry using a convex hyperboloidal subreflector and paraboloid main reflector.

CATA—Community Antenna Television Association. U.S. cable TV industry association.

CATV—Community Antenna (Cable) Television.

C-band—Used loosely for satellite services in the 6/4 GHz bands.

CBC—Canadian Broadcasting Corporation.

CBD—"C-band Direct" (broadcast). Proposed name for a formalized home TVRO system in the US.

CBS—Columbia Broadcasting System. Major U.S. network.

CCI—Co-Channel Interference.

CCIR—International Radio Consultative Committee.

CCITT—International Telegraphy and Telephony Consultative Committee.

CDMA—Code Division Multiple Access. (Also see SSMA).

Channel—a one-way communications link. The connections for satellite television transmissions are called channels. The volume of satellite television usage is measured in hours per channel.

Chrominance (Chroma)—The video color information.

C/I—Carrier-to-Interference ratio.

Circuit—A two-way communications link, most commonly used for sending and receiving voice and data information. Satellite capacity is most often stated in the number of circuits that a satellite can carry.

Clamp (also Line Clamp, Black Level Clamp)—A video processing circuit that removes low-frequency disturbances (e.g., energy dispersal) from the waveform.

Clarke Orbit—see GEO.

C-MAC—see MAC.

CNN—Cable News Network (US). American news service transmitted worldwide via satellite.

C/No or C/kT—Carrier/Noise Density, i.e., CNR per unit bandwidth.

CNR or C/N or C/kTB—Carrier-to-Noise Ratio, measured at RF or IF.

Code Division Multiple Access (CDMA). A transmission system that superimposes the audio or data information onto a specific coded address waveform. (Also see spread spectrum multiple access or SSMA).

Codec—Coder/Decoder system for digital transmission, e.g. of television.

Collocation—Ability of multiple satellites to share the same approximate geostationary orbital assignment.

Color Burst—A synchronizing signal contained within the composite video waveform which serves as a frequency and phase reference for the chrominance information.

Color Subcarrier—A subcarrier which is added to the main video signal to convey the color information. In NTSC systems, the color subcarrier is centered on a frequency of 3.579545 MHz, referenced to the main video carrier.

Common Carrier—A company providing telecommunications services to users under rates and regulations set by the Federal Communications Commission.

Companding—A noise-reduction technique involving compression applied at the transmitter, with complementary expansion at the receiver.

Composite Baseband—The raw demodulator output, prior to filtering and clamping and (usually) prior to deemphasis. Contains all transmitted subcarriers. In some receivers this output is not intended for video use, and a roll-off may be applied to the lowest baseband frequencies.

Composite Signal—Ambiguous term, variously used to refer to composite baseband or composite video.

Composite Video—Complete video signal including synchronizing, luminance and color information, with Teletext where transmitted. Does not include audio or data subcarriers.

COMSAT—Communications Satellite Corporation. U.S. corporation providing operational and technical services to INTELSAT, and operating its own domestic satellite systems.

Conical-scan—A complex type of autotracking system.

CONUS—contiguous United States.

Co-Polar(ized)—Of the same polarization.

CP—Circular Polarization.

Cross-Polar(ized)—Of the opposite polarization.

Cross-Site—Link or cable connection between antenna and equipment building.

CSDRN—Central Satellite Data Relay Network (Russian Federation).

CSG—Guyana (French Guiana) Space Centre at Kourou—launch base for Arianespace operations.

C/T—Carrier-to-noise-Temperature ratio.

CTS/Hermes—Communications Technology Satellite. Early experimental Canada/USA high-power 12-GHz satellite.

CTV—Canadian Television Network.

D/A—Digital/Analog (Conversion). (Also see DAC.)

DAC—Digital to Analog Conversion. Recovery of original analog signal from digital data.

DAMA—Demand-Assigned Multiple-Access. A spectrum-efficient method of dynamically allocating telephony channels in a transponder. (Also see SPADE).

DAP—Double Amplitude Peak. Peak-to-peak measurement (especially of a composite video signal).

dB—deciBel. A means of expressing ratios logarithmically. Number of dB = 10 x log(base 10) of power ratio. So, 3 dB represents a factor of 2, 10 dB a factor of 10, 20 dB a factor of 100, etc.

dBi—dB antenna gain relative to an isotropic source.

DBM—Double-Balanced Mixer.

dBm—dB power relative to one milliwatt.

DBP—Deutsche Bundespost (German PTT).

DBS—Direct Broadcasting (by) Satellite.

dBW—dB power relative to one watt.

DCT—See Discrete Cosine Transform.

DE—De-emphasis.

Declination—Angle between antenna beam and equatorial plane (measured in meridian plane). The offset angle of an antenna from its polar mount axis.

Decoding Margin—The extent by which SNR (or Eb/No) exceeds a value giving an unacceptable BER. (Also Eye Height.)

De-emphasis—Restoration of flat baseband frequency response after demodulation: the inverse of pre-emphasis.

Delta Modulation—Digital coding system based on the transmission of a change in value, rather than the absolute value of a sample. Exhibits a softer threshold than PCM.

Demodulation—The recovery of baseband information from a modulated carrier (see modulation).

Demod—Demodulator.

Demux—Demultiplexer.

Derived Circuit—The created circuits derived from the bearer circuit. The number of actual voice circuits being carried.

Deutsche Welle—Germany's external broadcasting service.

Deviation—The level of modulation of an FM signal—the extent by which the baseband or subcarrier signal shifts the main carrier frequency.

Differential Gain/Phase—Video (color) non-linear distortion parameters.

Digital—Signals which only have two distinct conditions, corresponding to the "on" (1) and "off" (0) logic states. (Also see analog).

Digital Video Compression—The transmission of oen or more TV signals in an abbreviated format that dramatically reduces the amount of frequency bandwidth required without substantially degrading the quality of the received image or images.

Discrete Cosine Transform—A mathematical algorithm used in digital video compression systems.

Discrimination—Measure of the ability of a component or system to separate wanted from unwanted signals, using some parameter such as polarization.

Discriminator—Type of FM demodulator.

Dispersal—See Energy Dispersal.

Dispersion—The effect of group delay of a wideband transmission channel changing with frequency, such that different time delays are imparted to components of different frequencies. Most noticeable with pulse signals. Not to be confused with Dispersal.

Dithering—See energy dispersal.

DFS/Postsat/Kopernikus—German domestic 12 and 20 GHz telecommunications satellite.

Domsat—Domestic Communications Satellite.

Downconversion—Translation of frequency or a block of frequencies to a lower portion of the electromagnetic spectrum, e.g. from SHF (microwave) frequencies to UHF or VHF.

Downlink—The space-to-Earth half of a two-way telecommunications satellite link. (Also see Uplink).

DPCM—Differential Pulse-Code Modulation (see PCM).

DPSK—Differential Phase-Shift Keying. (see PSK).

DR—Danmarks Radio. Radio Denmark, distributed to Greenland via INTELSAT.

DRO (or DSO)—Dielectric-Resonator (or Dielectrically-Stabilized) Oscillator. Highly stable oscillator circuit used in LNBs and BDCs.

DSI—Digital Speech Interpolation. A spectrum efficient mode for telephony transmission that takes advantage of the pauses tha occur in conversations to insert additional signals for transmission.

DSO—See DRO.

DSS—Direct Satellite Service (of UPITN). International television news distribution services via INTELSAT.

Dual spin—Spacecraft configuration in which the main body spins to provide attitude stabilization, and the antenna assembly (and often some of the electronics) are de-spun by means of a motor and bearing system, to point continuously towards the earth.

D2-MAC—see MAC.

Eb/No—Energy-per-Bit-to-Noise-power-density ratio. The digital equivalent of C/No.

EBT—Brazilian Educational TV network transmitted by the Brazilsat satellite system.

EBU (also UER)—European Broadcasting Union.

Echo Effect—A time-delayed electronic reflection of one's voice caused by an electrical discontinuity in a telephone circuit. Echoes are often experienced during satellite-delivered long distance telephone calls.

Echo canceller—An electronic circuit which attenuates or eliminates the echo effect on satellite telephony links.

Eclipse—Period when the satellite passes into the Earth's (or the Moon's) shadow, when power must be drawn from storage batteries.

Eclipse-protected—Refers to a transponder that can remain powered during the period of an eclipse.

ECS—European Communications Satellite. (Also see Eutelsat.)

ED—Energy Dispersal.

Edge of Coverage—Limit of defined service area, typically 3 dB down from beam center, but may be more. Reception is still possible beyond this line. (Also see Spillover.)

EIA—Electronic Industries Association.

EIRP (or e.i.r.p.)—Equivalent Isotropically Radiated Power (or Effective Isotropic Radiated Power). Combined result of transmitter (or transponder) RF power, and transmitting antenna gain.

Ekran ("Screen")—Soviet UHF DBS satellite serving the Statsionar-T system. Downlinks at 714 MHz to Siberia, but has usable coverage throughout Asia. Located 99 degrees E.

El/Az (El over Az)—An antenna mount providing independent steering in Azimuth and Elevation.

Electromagnetic Spectrum—The entire range of wavelengths of electromagnetic radiation—including visible light—which extend from gamma rays to microwaves and radio waves, all of which travel at the speed of light (186,000 miles per second or 300,000,000 meters per second).

Elevation—Angle between antenna beam and horizontal plane (measured in vertical plane).

Energy Dispersal—A low-frequency waveform added to the baseband signal before modulation, to reduce the FM signal's peak power per unit bandwidth, and thus its

interference potential.

EOL—End of Life (of a transponder or satellite).

Equatorial Mount—Astronomers' term for Polar Mount.

Equitorial Orbit—An orbit with a plane that is parallel to the Earth's equator.

ESA—European Space Agency.

ESDRN—Eastern Satellite Data Relay Network (Russian Federation).

ETR—Eastern Test Range (also Eastern Space and Missile Center), Cape Canaveral, Florida, US. (Also see KSC.)

Eurovision—The EBU's European program exchange network. Eurovision occupies two transponders, plus reserves, on a Eutelsat satellite.

Eutelsat—European Telecommunications Satellite Organization.

EVN—Daily Eurovision News exchange, relayed via Eutelsat and Intelsat.

Exciter—The modulator and driver section of a transmitter, as used in an uplink.

Eye Height—A measurement of SNR on a digital bitstream.

f/D—Focal-length-to-Diameter ratio (of a reflector).

Faraday Rotation—When peak sunspot activity highly charges the Earth's ionosphere, the vectors of linearly polarized satellite signals can be rotated or "twisted" through interaction with the Earth's atmosphere.

FDM—Frequency Division Multiplex.

FDMA—Frequency Division Multiple Access.

FEC—Forward Error Correction. Coding technique used in digital transmission.

Feed, Feedhorn, Feed Antenna, Feed System—The small, widebeam antenna that illuminates (gathers signal from) the reflector in an antenna system (convention speaks of illumination, even in a receive- only application, as if the antenna were transmitting).

Feeder, Feed Line—Co-axial cable transmission line connecting outdoor and indoor units.

FET—Field-Effect Transistor. Semiconductor device used in LNAs, LNBs, and LNCs. See also GaAs.

Field—One vertical scan of a TV raster; half of an interlaced frame or picture.

FM—Frequency Modulation. The baseband signal is caused to vary the frequency of the carrier wave.

FMFB—Frequency Modulation Feedback, a technique for deviation reduction and threshold extension.

FM Cubed—A proprietary method for the digital transmission of numerous audio and data signals within a single satellite transponder.

FM Squared—A method for the satellite transmission of analog audio signals on subcarriers without the presence of a composite video signal.

Footprint—Coverage area of a satellite beam; a contour map showing EIRP, SFD, PFD, antenna size, or G/T contours within a satellite's coverage zone.

Frame—In TV, the composite of two separate interlaced "fields" containing the even- and odd-numbered lines in NTSC, PAL and SECAM TV broadcasts. In PCM, one fixed length page or block of data, bounded by synchronization words.

Frame Rate—The number of times per second, expressed in units of Hertz, that a complete frame of video is displayed on the TV screen—50 Hz for European PAL and SECAM transmissions and 60 Hertz for NTSC and Brazilian PAL transmissions.

FR3—France Regions 3. French TV's third terrestrial network.

Frequency—The number of times that an alternating current goes through its complete cycle in one second of time. One cycle per second is also referred to as a Hertz, 1,000 cycles per second a kiloHertz, 1,000,000 cycles per second a megaHertz, and 1,000,000,000 cycles per second a gigaHertz.

Frequency reuse—a technique which maximizes the capacity of a communications satellite through the use of spacially-isolated beam antennas and/or the use of dual polarities.

FSK—Frequency shift keying.

FSS—Fixed-Satellite Service (see also BSS).

G—Giga-, one (US) billion or 10^9

GaAs—Gallium Arsenide. High-mobility semiconductor material used in low-noise microwave devices.

Gals ("Tack")—Russian DBS satellite system.

Gateway—A network access point. An interchange between two networks, for instance between national and international telecommunications networks (INTELSAT Gateway).

GEO—The Geosynchronous Equatorial (Clarke) Orbit. Unique orbit in which a body can remain essentially stationary relative to Earth co-ordinates.

Geosynchronous—Prograde orbit having a period equal to that of Earth's rotation (need not imply geostationary).

Geostationary—see GEO.

GHz—Unit of frequency equal to 1000 MHz, one billion (10^9) cycles per second.

Global Beam—Beam covering the entire visible Earth surface, (42 percent of the globe) as seen from the satellite.

GMT—Greenwich Mean Time. The international universal standard time. See also UT.

Gorizont ("Horizon")—Russian FSS satellites serving the Statsionar system in the 6/4, 8/7, and 14/11 GHz bands.

Grand Alliance—An organization formed by AT&T, David Sarnoff Research Center, General Instrument, MIT, Philips, Thomson, and Zenith to jointly develop a HDTV system for the United States.

Gregorian—Dual-reflector antenna geometry using a concave ellipsoidal subreflector and paraboloidal main reflector.

Group Delay—A signal distortion parameter.

G/T (G upon T)—Gain-to-noise-Temperature ratio of a receiving system; its sensitivity "Figure of Merit."

GTO—Geostationary (Geosynchronous) Transfer Orbit.

Guard Band—An unused spectra of frequencies which lie above and below each transponder. The guard band helps to prevent adjacent communications signals from interfering with one another.

HACBSS—Homestead and Community Broadcasting Satellite Service. Remote area DBS service via AUSSAT.

Half Circuit—The uplink and downlink between the same earth station and a satellite.

Half-Transponder—A method of transmitting two TV signals through a single transponder, by reducing the deviation and power allocated to each. Half-transponder TV carriers each operate typically 4 dB to 7 dB below single-carrier saturation power.

HDTV—High Definition Television. An advanced TV transmission system with a 16:9 aspect ratio and more than twice the number of active lines offered by NTSC, PAL and SECAM based systems.

Headend—Central distribution point for a CATV or MATV system.

Head Unit—Alternative term for an LNA, LNB, or LNC. Also termed outdoor unit.

Hemispheric Beam—Shaped beam covering approximately half of the visible Earth's surface (21 percent of the total globe), as seen from the satellite. INTELSAT spacecraft carry East and West hemispheric beams, while Russian Gorizont and Raduga satellites are equipped with Northern hemispheric beams illuminating the visible portion of the globe which lies North of the equator.

HEMT—High Electron Mobility Transistor.

Hermes —see CTS.

Hertz—A unit of frequency. One cycle per second. (Also see frequency.)

High Power Satellite—Satellite with transponder RF power in excess of about 100W.

Hour Angle—Angle between antenna beam and meridian plane (measured in equatorial plane). Steering direction of a polar mount antenna.

HPA—High-Power Amplifier (esp. in an uplink). Usually a TWTA or a Klystron. See also SSPA.

HPF—High-Pass Filter.

Hue—Spectral tint parameter in a color video signal.

Huffman Coding—A variable length coding system used in compression systems.

Hz—Hertz—unit of frequency. One cycle per second.

IBA—Independent Broadcasting Authority (UK).

IBS—International (or INTELSAT) Business Services.

IDR—International Digital Route. The digital equivalent of the analog FDM/FM voice service used by INTELSAT.

IF (or i.f.)—Intermediate Frequency (in a receiver).

IFL—Inter-Facility Link. Anything from a cross-site transmission line to a complete data network.

IFRB—International Frequency Registration Board (of ITU).

IMD—Intermodulation Distortion (in non-linear system).

Inclination—Angle between orbital plane of satellite and equatorial plane of Earth.

Indoor Unit—see TDM (2).

Injection Locking—Low-cost technique for phase-locking a cavity or resonator oscillator to a crystal source, to improve its frequency stability.

INMARSAT—International Maritime Satellite Organization. Uses Inmarsat, Marisat, Marecs, and INTELSAT V MCS satellites.

INSAT—Indian National Satellite System.

INTELSAT—International Telecommunications Satellite Organization (and its satellites). The global telecommunications satellite system. INTELSAT's membership totaled 134 nations in 1994.

Interferometer Feed—Antenna feed generating controlled pattern of sidelobes and nulls, to permit use of small antennas with closely-spaced satellites.

Interlaced Scanning—In standard TV broadcast systems, the odd-numbered lines are transmitted in the first video "field" and the even numbered lines are subsequently transmitted in a second video field. The entire image, or "frame", which is an interlaced composite of these two separate fields, is perceived as a single image because of the high speed at which the two fields are transmitted.

Intersatellite Link—A transmission path directly between two communications satellites.

Intersputnik—International telecommunications satellite organization. Uses Gorizont, Raduga and Luch (Loutch) satellites.

IOR—Indian Ocean Region (as defined by INTELSAT).

IPA—Intermediate Power Amplifier (in an uplink transmitter).

ISDN—Integrated Services Digital Network. A high quality global telecommunications network based on digital technology. ISDN is designed to allow subscribers to access a multiplicity of communications services through a single point or connector in the network.

ISO—International Standards Organization.

Isolation—The measure of separation (as dB or power ratio) between two potentially interfering signals, e.g. in different beams or on different polarizations.

Isolator—Transmission-line component which passes signals with low loss in a preferred direction, while presenting high attenuation in the reverse direction.

Isotropic—The property possessed by a hypothetical omnidirectional point-source antenna, the reference for antenna gain measurements.

ITS—Insertion Test Signal (also VITS) for monitoring a channel's video performance parameters.

ITU—International Telecommunications Union.

IUS—Inertial Upper Stage (for GEO launches). A type of PKM.

IVN—Intervision News exchange, distributed via Intersputnik.

J-Hook (or button-hook)—Prime focus feed system with rear flange, connected via hook-shaped waveguide run.

k—Kilo-, one thousand or 10^3

K—see Kelvin.

K-band—The frequency spectrum 10.9 to 36 GHz.

Ka-band—Used loosely for 30/20 GHz satellite systems.

kb/s—Kilobits per second (digital bit-rate).

Kelvin, K—Unit of absolute temperature, used in noise measurement. 273 Kelvin equals zero Celsius. Also degrees Kelvin, degrees absolute.

Klystron—Type of high-power beam tube used in some HPAs.

Kopernikus—see DFS.

Kosmos—Name given to non-specific Soviet satellites—includes some experimental communications payloads.

Kourou—Location of Guyana Space Centre (see CSG).

KSC—Kennedy Space Center (Cape Canaveral).

Ku-band—Used by satellite systems employing frequencies between 10.7 and 18 GHz.

Landsat—An earth resources technology satellite.

Latitude—The distance, expressed in degrees, from the Earth's equator to points North or South. The equator is assigned a value of 0 degrees; North and South poles are 90 degrees.

L-band—Used loosely of satellite systems downlinking in the region of 1.6 GHz.

LEO—Low Earth Orbit.

LEOsat—Proposed mobile satellite systems using LEO.

LHCP (or LCP)—Left-Hand Circular Polarization.

Line Displacement—Type of video scrambling (e.g., Dis-

crete)

Line Rotation—Type of video scrambling (e.g., Linkabit).

Link Budget—The calculation of power and noise levels between transmitter and receiver (uplink or downlink), taking account of all gain and loss factors, to yield operating values of C/I and C/NR, margin above threshold, and ultimate S/NR or BER.

Link Margin—The extent (in dB) by which normal working (or clear sky) C/NR exceeds threshold C/NR, or other value at which reception is deemed unusable.

LNA—Low-Noise Amplifier.

LNB (or LNBC)—Low-Noise Block (downconverter). A type of LNC.

LNC—Low-Noise Converter (term can include LNB).

LNF—A combination of a feed, automatic polarizer and low noise amplifier in a common package.

Longitude—The distance in degrees from one meridian to any other is defined in terms of degrees of longitude. (Also see meridian and latitude).

Look Angle—The angle between the horizon and the amount an earth station antenna is tilted up to receive signals from, or send signals to, a satellite.

LOS (1)—Loss of Signal.

LOS (2)—Line of Sight.

Loutch—See Luch.

Low Power Satellite—Satellite with transponder RF power below about 30 watts.

LPF—Low-Pass Filter.

Luch (or Loutch)—Russian Ku-band telecommunications system. Exists in pre-operational form on Gorizont and SDRN satellites downlinking using Ku-band frequencies.

Luminance—Light and shade information in a video signal.

m—Milli-, one-thousandth or 10^{-3}.

M—Mega-, one million or 10^{6}.

MAC (A-, B-, C- or D-)—Multiplexed Analogue Components color system, with various types of sound and data channels.

Margin—See Link Margin, Decoding Margin.

Marginal—Describes a system operating with nil, or inadequate, margin.

Marisat—Maritime Telecommunications Satellite.

MASER—Microwave Amplification by Stimulated Emission of Radiation. Cryogenic LNA used in early Earth Stations.

MATV—Master Antenna Television—private cable. (Also see SMATV).

Mb/s—Megabits per second (also expressed as Mbits/s).

MBA—Multiple Beam Antenna.

MBTA—Multiple Beam Torus Antenna (Comsat design)

MCS—Maritime Communications System (on INTELSAT V).

MDS—Microwave Distribution System.

Medium Power Satellite—Satellite with transponder RF power in the region of 30W to 100W.

MEO—Medium Earth Orbit.

Meridians—Lines circling from pole to pole which cross each of the 360 degrees which comprise the Earth's equator.

Mesh Network—A VSAT system design where each terminal in the networks can directly communicate with any other terminal without the aid of a central "hub" station. (Also see Star Network.)

MMDS—Multi Microwave Distribution System.

Modem—Modulator/demodulator. Usually applied to a device for converting digital data to audio tones (and vice versa) for transmission via an analog channel.

Modulation—The impression of information upon an RF carrier wave, by varying some parameter of that wave.

Modulator, AM—Consumer satellite receivers are equipped with a VHF or UHF remodulator to supply a standard AM TV channel to the home TV receiver.

Modulation Index—The ratio of peak deviation to highest modulating frequency, in an FM system.

Molniya ("Flash")—Non-geosynchronous communications satellites serving the Russian Orbita system in the 6/4 GHz band.

Monopulse—Hardware-based automatic antenna tracking system.

Morelos—Mexican domestic satellite system (formerly Ilhuicahua).

Morya ("Seamen")—Russian maritime communications satellite system.

Moskva—Moscow. The name given to the Russian Federation's small antenna domestic TV and radio distribution system, using Gorizont satellites downlinking in spot beams at 3.675 GHz.

Motion Compensation—A technique used in digital video compression systems to compute the direction and speed of moving objects within the video image.

MPEG—Motion Picture Experts Group. A technical committee of the International Standards Organization of the ITU established to recommend worldwide standards for the compressed representation of multimedia.

MPEG 1—The compression standard developed for a wide variety og progressive scan (non-interlace) sources of multimedia, including text, graphics, photos audio and motion pictures.

MPEG 2—The compression standard developed for interlace scan sources of multimedia, including broadcast TV and videotaped program resources.

MSO—Multiple System Operator. A company operating several CATV systems.

Multiburst—A video test waveform included in ITS.

Multiplexing (1)—The combining of multiple signals into a single composite transmission which occupies the total available channel bandwidth.

Multiplexing (2)—The offering of multiple, time-delayed versions of satellite-delivered program servicesto dramatically expand program access for cable and satellite TV viewers.

Multipoint—A single communications line or circuit interconnecting several stations. Use of this type of line ususally requires some kind of polling mechanism to address each terminal with a unique address code.

Mux—Multiplexer.

NAB—National Association of Broadcasters. U.S. broadcast industry association, and its annual convention.

NASA—National Aeronautics and Space Administration. U.S. agency which administers the American space program, including the deployment of military satellites via its fleet of space transportation system (STS).

NASDA—National Space Development Agency of Japan.

NBC—National Broadcasting Company. Major U.S. TV network.

NCTA—National Cable Television Association. U.S. cable TV industry association.

NII—National Information Infrastructure.

Noise Figure—Measurement of noise contribution of an amplifier relative to a noise-free amplifier at a reference temperature. Usually expressed in dB.

Noise Measure (of an amplifier).—The Noise Figure of a theoretical infinite chain of identical amplifiers.

Noise Temperature—Noise measurement of a system, as the absolute temperature of a resistive source delivering equal noise power. Expressed in (degrees) Kelvin.

Novosti—Soviet press agency.

NRK—Norsk Rikskringkasting. Norwegian state TV service.

NTSC—National Television Standards Committee (of U.S.—used in reference to the U.S. color TV system).

Nutation—The imbalance associated with a spinning object.

OBM—Out of band noise.

Offset-fed Antenna—An antenna whose reflector forms only part of a paraboloid of revolution, usually excluding the pole or apex, such that a front feed causes no aperture blockage.

OIRT—International Radio and Television Organization, headquartered in Prague.

Olympus—European experimental communications satellite which failed in orbit on May 29, 1991.

OMT—Orthogonal-Mode Transducer or ortho-coupler; waveguide component that separates or combines two orthogonally polarized signals.

O-QPSK—See QPSK.

Orbita—The Soviet satellite television distribution system.

Orbital Period—The time that it takes a satellite to completely circumnavigate its orbit.

Orthogonal—Mutually at right angles (e.g., horizontal and vertical polarization, right- and left-hand circular polarization).

OSI—Open Systems Interconnection model developed by

the International Standards Organization to foster universal compatibility between various communications networks.

OTS—Orbital Test Satellite. Pre-operational test vehicle for European Communications Satellite.

Outage—See Solar Outage and Rain Outage.

Outdoor Unit—see Head Unit.

Packet Switching—The transfer of data by means of addressed packets whereby a channel is only occupied for the duration of transmission of the packet. The channel is then available for the transfer of other packets.

PAL—Phase Alternation (by) Line. German-designed color TV encoding system.

Palapa—Indonesia/ASEAN regional satellite system.

PAM (PAM-D)—Payload Assist Module (for GEO launches). A type of PKM.

Paraboloid—A parabola of revolution. Classical shape of antenna reflector.

Paramp—Parametric Amplifier. Sophisticated type of LNA.

PBS—Public Broadcasting System (US).

PCM—Pulse Code Modulation. Coding system for digital transmission.

PE—Pre-emphasis.

Peltier—Thermoelectric cooling system for cryogenic LNAs.

Perigee—Lowest point (minimum altitude) of a geocentric orbit. See also Apogee.

Period—Time taken for a satellite to make one complete revolution of its orbit.

p.f.d. (or PFD)—Power-Flux Density (related to field strength).

Pilot Tone—A reference frequency transmitted as part of an SCPC system, or a baseband control signal in a companding system.

Pixel—Picture Element in a video imaget.

PKM—Perigee Kick Motor. Rocket motor fired to inject a satellite into GTO.

Planar Array—Flat satellite antenna composed of a gridwork of tiny resonant elements.

PLL—Phase-Locked Loop (type of demodulator).

PM—Phase modulation.

Point-To-Point—A communications line connected directly from one point to one other point as opposed to multipoint lines.

Polar Mount—Antenna mechanism permitting steering in hour angle (i.e., along the GEO arc) by rotation about a single axis. Also Equatorial Mount. A classical polar mount has its axis parallel to that of the Earth. TVROs use modified polar mount geometry, incorporating a declination offset.

Polar Orbit—An orbital path located along the plane of the Earth's polar axis.

Polarization—The property by which an electromagnetic wave exhibits a direction (or rotation sense) of vibration, giving the opportunity for frequency re-use by orthogonal polarizations.

Polarizer (also De-Polarizer)—A bi-refringent component in a waveguide or antenna system, which converts between linear (plane) and circular polarizations. Not a polarization rotor.

Polarization Rot(at)or—A device that permits selection of one of two orthogonal polarizations, or of any polarization angle. Not a polarizer.

Polarotor—A proprietary name for a type of polarization rotor, a transition with a remotely-rotatable probe.

POR—Pacific Ocean Region (as defined by INTELSAT).

Potok—Proposed Russian C-band domestic telecommunications satellite.

PRC—People's Republic of China (satellite system).

Pre-emphasis—A method of improving S/NR in an FM system, by increasing deviation at high (relative to low) baseband frequencies, according to a defined (BG or CCIR) function.

Preemptive transponder—A transponder which is sold or leased under the condition that it can be supplied in an emergency to primary customers which have leased or purchased protected transponders from the selling or leasing entity.

Prime Focus—The focal point of a paraboloid reflector. A feed system placed at that point.

Progressive Scanning—Widely used in computer displays, progressive scanning transmits each line in a video image in sequence until the entire image or "frame" has been traced onto the TV screen. Also known as non-interlaced or sequential scanning.

Proton—Russian D-class heavy launch vehicle (used for Statsionar flights).

Prograde—Being or relating to orbital or rotational motion of a body that is in the same direction as that of another celestial body. (Also see Geosynchronous).

Protected Transponder—Entities which lease or purchase protected transponders are guaranteed access by the supplier to a backup transponder in the event that the primary transponder fails. (Also see preemptive transponder).

PSK—Phase-Shift Keying (type of digital modulation).

Psophometry—A type of channel noise measurement.

Pulse and Bar—A video test waveform, included in ITS.

Pulse width modulation, PWM—An audio transmission format used by the Russians to transmit the TV sound signals within the video's horizontal blanking interval.

QDBS (or Q-DBS)—Quasi-DBS. The use of FSS satellites to provide a broadcasting service.

QPSK—Quadrature Phase-Shift Keying (see PSK).

Raduga ("Rainbow")—Russian FSS satellite serving the Statsionar system in the 6/3.4 GHz band.

RAI—Radiotelevisione Italiana. First and second chains, RAI-Uno and RAI-Due, are distributed via Eutelsat.

Rain Outage—Loss of signal (esp. at Ku-band) due to absorption and thermal noise accompanying heavy rainfall.

Range—see Slant Range.

RARC—Regional Administrative Radio Conference. See WARC.

RCI—Radio Canada International. Overseas radio service, distributed via INTELSAT.

Real Time—A telecommunications or data processing system that responds immediately, in the same time frame as the user provides input.

Repeater—see Transponder.

Reuters—International news agency.

RF—Radio Frequency.

RGB—Red, Green, Blue. The three primary color components in a TV system. See also YUV.

RHCP (or RCP)—Right-Hand Circular Polarization.

RRO—Radio Receive-Only (terminal).

RTA—Radiodiffusion-Television Algerienne. Algerian TV is distributed via Indian Ocean INTELSAT satellite.

RTL—Radio-Tele-Luxembourg.

RTM (1)—Radiodiffusion Television Marocaine. Moroccan TV is distributed via INTELSAT.

RTM (2)—Radio Television Malaysia. RTM program services are distributed by the Palapa C1 satellite.

RTP (1)—Radiotelevisao Portuguesa. Part of Portuguese Television's output is linked to Madeira and the Azores, via INTELSAT.

RTP (2)—Radio Televisora Peruana. Channel 7 in Lima, Peru is transmitted by INTELSAT to locations throughout the Americas.

RTVE—services TVE-1, TVE-2 and TVE International are transmitted by INTELSAT.

SAT 1 (formerly PKS)—West German cable TV service, distributed by TV Sat, Astra and DFS Kopernikus satellites.

SatStream—BTI's satellite business services.

Saturation (1)—Operating point of a non-linear amplifier when drive level is adjusted to obtain maximum output.

Saturation (2)—Color intensity parameter in a video signal.

SAW—Surface Acoustic Wave (IF filter technology).

S-band—Satellite downlinks in the region of 2.6 GHz.

SBS—Satellite Business Systems (Satellites now owned by Hughes Communications).

SBTS—Sistema Brasileiro de Telecomunicacoes por Satelite, the Brasilsat system.

S/C—see subcarrier.

Scalar Feed—The wide flare corrugated horn antenna feed, now standard in 4-GHz home TVRO. Hybrid modes contribute to pattern symmetry, high efficiency, and XPD.

SCPC—Single Channel Per Carrier (transponder usage).

SCPT—Single Carrier Per Transponder.

SDS—SPELDA Delivery System. (See SPELDA.) Also a class of communications satellites which can be launched with a second communications satellite using the SPELDA dual launch payload adapter.

SECAM—Sequence Couleur a Memoire. French-designed color TV encoding system.

Shaped Beam—Beam of irregular cross-section, produced by multiple feed or shaped reflector techniques.

Shaped Reflector—Techniques for controlling beam pattern, aperture illumination, noise, and sidelobe power, and for increasing antenna efficiency, by variation of antenna (and subreflector) shape from the true paraboloid, hyperboloid etc.

Sidelobe—Off-axis response of an antenna.

Sirio—Italian experimental Ku-band communications satellite.

SiS—Sound-in-Syncs (audio/video multiplexing system). Strictly refers to the digital version used by EBU.

Skew—The difference (real or apparent) in linear polarization angle between two (or more) different satellites, as modified by mount geometry.

Slant Range—Path length between satellite and Earth station.

SMATV—Satellite Master Antenna Television (see MATV).

SMS (1)—Satellite Multi-Services; name of the Eutelsat business-satellite services.

SMS (2)—Sistema Mexicano de Satelite. See Morelos.

S/N—See S/NR.

S/NR—Signal-to-Noise Ratio. A measure of how clean (noise- free) the recovered baseband signal is.

Solar Array—A network of solar cells which generate electricity from sunlight.

Solar Eclipse—When the Earth shadows the satellite's solar array from the Sun.

Solar Outage—Loss of signal caused by the sun passing through the receiving antenna's beam.

SPADE—Single-channel-per-carrier, PCM multiple-Access Demand-Assignment Equipment (SCPC telephony sys.).

Sparklies—Popular term for impulse noise spikes visible as black or white spots or streaks in the TV picture, at CNR values close to threshold.

SPELDA—Dual payload launch adapter for Ariane.

Spherical—Simple geometry for feed-steerable or multiple beam antenna.

Spillover—Usable (but often unwanted) signal reaching locations beyond defined Edge of Coverage.

Spin stabilization—A form of satellite attitude control which is achieved through spinning the exterior of the spacecraft about its axis at a fixed rate.

Splashplate—Component of a backfire feed system—an unshaped (or arbitrarily shaped) subreflector.

Spot Beam—Beam of circular or elliptical cross-section, covering a defined region of the Earth's surface, small in relation to a global beam.

SSB—Single Side Band. A form of amplitude modulation (AM) whereby one of the sidebands and the AM carrier are suppressed.

SSMA—Spread Spectrum Multiple Access. (Also see CDMA).

SSPA—Solid-State Power Amplifier. A transistor or FET HPA now increasingly replacing TWTs in satellite transponders.

SS-TDMA—Satellite-Switched Time Division Multiple Access.

Stairstep (UK Staircase)—A video test waveform, included in ITS.

Star Network—A VSAT system configuration consisting of a central "hub" station which controls and monitors an associated network of VSAT terminals.

Stationkeeping—Orbital adjustments to maintain satellite accurately at desired geostationary location.

Statsionar—Russian geostationary communications satellite systems. See Intersputnik, Ekran, Gorizont, Raduga.

Step-Track—Software-based automatic antenna tracking system.

STIA—Satellite Television Industry Association. U.S. satellite industry group previously known as SPACE.

STL—Studio-Transmitter Link.

STS—Space Transportation System (the Shuttle).

Subcarrier—An information-carrying wave, which in turn modulates the main carrier in a communications system. Subcarriers are used for color information, TV audio, independent audio, and data transmission.

Subsatellite point—The unique spot over the Earth's equator assigned to every geostationary satellite.

Symphonie—Experimental Franco-German C-band sat-

ellite. The operational precursor of Telecom-1.

Sync Suppression—Type of video scrambling (e.g., Oak Orion, Nimrod).

Tanegashima—Japanese space center.

TASS—Russian news agency.

TC—Telecommand (control of a satellite).

TDA—Tunnel Diode Amplifier (early type of LNA).

TDF—French DBS satellite system.

TDM (1)—Time Division (or Domain) Multiplex.

TDM (2)—Tuner/Demodulator (i.e., Indoor Unit). Often referred to as the receiver.

TDMA—Time Division Multiple Access.

TDRS(S)—Tracking and Data-Relay Satellite (System) used by NASA.

Telecom —French domestic telecommunications satellite system.

Téléglobe—Canada's international satellite operator, national representative for INTELSAT.

Tele-Sahel—Government-owned national TV network of Niger which is transmitted by an INTELSAT satellite.

Telesat—Canada's domestic satellite organization, operating the Anik system.

Teletex—A textual data transmission system, linking word processing terminals.

Teletext—Broadcast Videotex. An on-screen text information service transmitted in digital format using spare lines in the VBI of a TV signal.

Telex—A telegraphic text transmission system, linking teleprinters.

Tele-X—Nordic DBS satellite system.

TF1—Television Francaise 1. French TV 1st channel.

Three-axis stabilization—Type of spacecraft stabilization in which the body maintains a fixed attitude relative to the orbital track and the earth's surface. The reference axes are roll, pitch, and yaw, by nautical analogy.

Threshold—In an FM system, the value of CNR at which the linear relationship between CNR and demodulated signal SNR breaks down. (Also see Sparklies).

Threshold Extension—Techniques for reducing the CNR value at which threshold effects occur.

Thruster—A small rocket engine used during routine stationkeeping activities.

TI—Terrestrial Interference. Interference to satellite reception caused by ground-based microwave transmitting stations.

TM—Telemetry. Satellite status data transmission.

TOC—Technical Operations Center.

Torus—Parabolic Torus geometry of multiple beam antenna. Reflector has a circular profile along the orbital arc, and a parabolic profile across the arc.

TP—Telephony.

Traffic—The telecommunications signals passing through a transmission channel, especially telephony, data.

Transfer Orbit—A highly elliptical orbit which is used as an intermediate stage for placing satellites into geostationary orbit.

Transmission Line—Structure providing a (usually low-loss) pathway for a radio-frequency signal. In satellite communications, usually coaxial cable or waveguide.

Transponder—The equipment forming a single repeater channel on board a satellite.

Truncation—Loss of outermost side frequencies of an FM signal due to filtering. Shows as "tearing" effect of noise on video transients, sharp vertical edges.

T/R—Transmit/Receive.

TT&C—Tracking, Telemetry, and Command (or Control).

TTC&M—Tracking, Telemetry, Command, and Monitoring. A satellite's controlling Earth Station.

TVRO—Television Receive-Only (terminal).

TV-SAT— German DBS satellite system.

TWT—Traveling-Wave Tube.

TWTA—Traveling-Wave Tube Amplifier.

UER—Union Europeenne de Radiodiffusion. See EBU.

UHF—The spectrum 300 MHz thru 3 GHz. Terrestrial broadcast television occupies 470~890 MHz. The 620~790 MHz band is allocated for community DBS downlinks in developing countries and remote areas, and is used by the Soviet Union (see Ekran).

Uplink—The space-to-Earth telecommunications pathway.

USIA—United States Information Agency. Operates its own international videoconferencing network via INTELSAT and Eutelsat.

UT—Universal Time. Same as GMT.

VBI—Vertical-Blanking Interval (of TV signal), in U.S. terminology. Otherwise known as field suppression.

VDU—Visual Display Unit. TV-type monitor used as a computer display.

VHRR—Very High Resolution Radiometer.

Videotex—An electronic textual information distribution system, from a central computer to remote VDUs. (Also see Teletext, Viewdata).

Viewdata—Interactive videotex.

Visnews—International TV news agency.

VITS—Vertical-Interval Test Signal (US); Vision Insertion Test Signal (Europe). See ITS.

VOA—Voice of America (overseas broadcasting service of the U.S. government). VOA radio programs are distributed via Eutelsat, INTELSAT and Satcom satellites.

Volna ("Wave")—Proposed Soviet mobile satellite communications system. Part of Volna plan may be realized with Morya system, using Gorizont locations.

VSWR—Voltage Standing Wave Ratio. A measurement of mismatch in a cable, waveguide, or antenna system.

VTO—Voltage Tuned Oscillator.

WARC—World Administrative Radio Conference. The ITU meetings that work out standards for international radio communications (including satellite TV). The next WARC is scheduled for 1992.

Waveguide—A rectangular or oval metal pipe that is commonly used as a transmission line for microwave signals. The dimensions and tolerances of waveguides are directly related to the wavelength of the microwave signals which they are to carry.

Wegener—Proprietary system for subcarrier stereo (or additional audio) transmission. Uses discrete low-level companded subcarriers.

Weighting—Correction of SNR measurements to take into account such factors as bandwidth and annoyance value.

WSMC—see WTR.

WSDRN—Western Satellite Data Relay Network (Russian Federation.).

X-band—Used loosely to refer to satellites operating in the 8/7 GHz range.

XEW, XHITM, XETV, XHDF—Mexican TV services distributed via Morelos.

XPD—Cross-polar discrimination (of an antenna).

X/Y—An antenna mount permitting independent steering about two orthogonal axes, not necessarily related to azimuth or elevation.

X,Y—The two planes of polarization in the Eutelsat system, nominally horizontal and vertical, respectively.

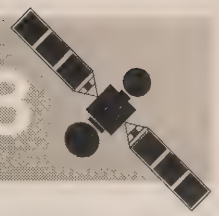
Y-Factor—A method of measuring Noise Figure and G/T.

Yagi—A communications antenna consisting of a main metal boom that supports numerous quarter-wave elements. Used for reception of S-band TV signals from Arabsat.

YUV—An alternative assembly of color components. Y is the Luminance signal, U and V are normalized versions of the Blue and Red color-difference signals, B-Y and R-Y.

Zone beam—Beam pattern, usually a shaped beam, intermediate between hemispheric and spot.

Appendix B



World TV Systems Standards

	CCIR System		Color System		Satellite Service Standard	Channelization			
Country	VHF	UHF	VHF	UHF		VHF	UHF	Voltage	Remarks
Afghanistan	B	None	PAL	None		CCIR	None	220(50)	
Albania	B	G	None	None		CCIR	CCIR	220(50)	
Algeria	B	None	PAL	None	PAL	CCIR	None	127/220/380(50)	
Angola	I	None	None	None		CCIR	None	220(50)	
Antigua	M	None	NTSC	None		USA	None	110(50)	
Argentina	N	None	PAL	None	PAL-N	USA	None	220(50)	3.58 MHz
Australia	B	None	PAL	None	PAL	Unique	None	240/415(50)	
Austria	B	G	PAL	PAL		CCIR	CCIR	220/380(50)	
Azores	B	None	PAL	None		CCIR	None	220(50)	
Bahamas	M	None	NTSC	None		USA	None	110/220(60)	
Bahrain	B	None	PAL	None		CCIR	None	2230(50)	
Bangladesh	B	None	PAL	None		CCIR	none	220/440(50)	
Barbados	N	None	NTSC	None		USA	None	110/220(50)	
Barbuda	M	None	NTSC	None		USA	None	110/220(50)	
Belgium	B	H	PAL	PAL		CCIR	CCIR	220(50)	
Belize								110/220(60)	
Benin	K'	None	None	None		CCIR	None	220/380(50)	
Bermuda	M	None	NTSC	None		USA	None	115/230(60)	
Bhutan								220(50)	No TV
Bolivia	M	N	NTSC	NTSC		USA	USA	110/220(50)	
Botswana								230(50)	No TV
Brazil	F	None	PAL	None	PAL-M	USA	None	110/127/220 (50/60)	3.58MHz
Brunei	B	None	PAL	None		CCIR	None	110/127/220(50)(60)	
Bulgaria	D	K	SECAM	SECAM	SECAM	CCIR	ORIT(R)	220(50)	
Burma	M	N	NTSC	NTSC		USA	USA	110/220(50)	
Burundi								220/380(50)	No TV
Cameroon								220/230(50)	No TV
Canada	M	None	NTSC	None	NTSC	USA	None	115/230(60)	
Canary Islands	B	None	PAL	None		CCIR	None	110/220(50)	
Canton Island								110/220(60)	No TV
Central Africa Republic								220(50)	No TV

	CCIR System		Color System		Satellite Service Standard	Channelization			
Country	VHF	UHF	VHF	UHF		VHF	UHF	Voltage	Remarks
Chad								220(50)	No TV
Chile	M	None	NTSC	None	NTSC	USA	None	220/380(50)	
Colombia	M	None	NTSC	None	NTSC	USA	None	115/220(60)	
Congo	D	None	None	None		CCIR	None	220(50)	
Costa Rica	M	None	NTSC	None		USA	None	120/220(60)	
Cuba	M	None	NTSC	None	NTSC	USA	None	115/220(60)	
Cyprus	B	G	PAL	PAL		CCIR	CCIR	240(50)	
Czechoslovakia	D	K	SECAM	SECAM	SECAM	ORIT(R)	CCIR	220(50)	
Denmark	B	None	PAL	None		CCIR	None	220/380(50)	
Diego Garcia	M	None	NTSC	None		USA	None	110/220(60)	
Djibouri	K'	None	SECAM	None		FOT U.	None	220(50)	
Dominica								240(50)	No TV
Dominican Republic		M	None	NTSC	None	USA	None	110(60)	
Dubai(UAE)	B	G	PAL	PAL		CCIR	CCIR	220(50)	
Ecuador	M	None	NTSC	None		USA	None	110/220(60)	
Egypt	B	None	SECAM	None		CCIR	None	127/220(50)	
El Salvador	K	None	NTSC	None		USA	None	110/220(50)	
Ethopia	B	None	None	None		CCIR	None	127/220(50)	
Faroe Islands	B	None	PAL	None		CCIR	None	220(50)	
Fiji								240(50)	No TV
Finland	B	G	PAL	PAL		CCIR	CCIR	220/380(50)	
France	E	L	SECAM	SECAM		Unique	CCIR	Various(50)	
Gabon	K'	None	SECAM	None		FOT U.	None	220(50)	
Gambia								230(50)	No TV
Germany	B	None	SECAM	None		OIRT(R)	None	220/380(50)	
Ghana	B	None	PAL	None		CCIR	None	230(50)	
Gibraltar	B	None	PAL	None		CCIR	None	240(50)	
Greece	B	H	SECAM	SECAM		CCIR	CCIR	220(50)	
Greenland	B	None	PAL	None		CCIR	None	220/380(50)	
Greenland	M	None	NTSC	None		USA	None	110/220(60)	
Grenada								220(50)	No TV
Guadeloupe	K'	None	SECAM	None		FOT.	None	220(50)	
Guam	M	None	NTSC	None		USA	None	110/220(60)	
Guatemala	M	None	NTSC	None		USA	None	110/120/127/220(60)	
Guyana								220(50)	No TV
Guiana-French	K'	None	SECAM	None		FOT U.	None	127/220(50)	
Guinea Republic	K'	None	SECAM	None		FOT U.	None	220/380(50)	
Guinea-Eq. I	B	None	None	None		CCIR	None	220/380(50)	
Haiti	M	None	NTSC	None		USA	None	110/220(50)(60)	
Holland	B	G	PAL	PAL	PAL	CCIR	CCIR	220(50)	
Honduras	M	None	NTSC	None		USA	None	110(60)	

	CCIR System		Color System		Satellite Service Standard	Channelization			
Country	VHF	UHF	VHF	UHF		VHF	UHF	Voltage	Remarks
Hong Kong	B	I	PAL	PAL		CCIR	CCIR	200(50)	
Hungary	D	K	SECAM	SECAM	SECAM	OIRT(R)	CCIR	220(50)	
Iceland	B	None	PAL	None		CCIR	None	220(50)	
India	B	None	PAL	None	PAL	CCIR	None	230/400(50)	
Indonesia	B	None	PAL	None	PAL	CCIR	None	127/220(50)	
Iran	B	None	SECAM	None	SECAM	CCIR	None	220(50)	
Iraq	B	None	SECAM	None		CCIR	None	220/380(50)	
Ireland	A	I	PAL	PAL		Unique	Unique	220/380(50)	
Israel	B	G	PAL	PAL	PAL	CCIR	CCIR	230/400(50)	
Italy	B	G	PAL	PAL	PAL	Unique	CCIR	220/380(50)	
Ivory Coast	K'	None	SECAM	None		FOTU.	None	220/380(50)	
Jamaica	M	None	NTSC	None		USA	None	110/220(50)	
Japan	M	M	NTSC	NTSC	NTSC	Unique	Unique	110/220(50)(60)	
Johnston Island	M	None	NTSC	None		USA	None	110/220(60)	
Jordan	B	G	PAL	PAL		CCIR	CCIR	220(50)	
Kampuchea								120/208/220(50)	
Kenya	B	None	PAL	None		CCIR	None	240(50)	
Korea-North	D	None	PAL	None		Unique	None	220(50)	
Korea-South	M	None	NTSC	None		USA	None	110(60)	
Kuwait	B	None	PAL	None		CCIR	None	240(50)	
Laos	M	None	None	None		USA	None	127/220(50)	
Lebanon	B	None	SECAM	none		CCIR	None	110/190(50)	
Lesotho								240(50)	No TV
Liberia	B	None	PAL	None		CCIR	None	120(60)	
Libya	B	None	SECAM	None	SECAM	CCIR	None	127/130(50)	
Luxembourg	C	G/L	PAL	PAL	PAL	CCIR	CCIR	110/220(50)	
Macau								110/220(50)	No TV
Madeira	B	None	PAL	None		CCIR	None	220/380(50)	
Madagascar	K'	None	SECAM	None		FOT U.	None	110/220(50)	
Malawi								230(50)	No TV
Malaysia(Peninsula)		B	None	PAL	PAL	CCIR	None	230/400(50)	
Mali								220(50)	No TV
Malta	B	H	PAL	PAL		CCIR	CCIR	240(50)	
Martinique	K'	None	SECAM	None		FOT.	None	200/380(50)	
Marshall Islands								110/220(60)	No TV
Mauritania	K'	None	SECAM	None		FOT.	None	200/380(50)	
Mauritius	B	None	SECAM	None		CCIR	None	240(50)	
Mayotte								220(50)	No TV
Mexico	M	None	NTSC	None	NTSC	USA	None	110/220(60)	
Midway Islands	M	None	NTSC	None		USA	None	110/220(60)	
Monaco	E	G/L	SECAM	PAL/SECAM		CCIR	CCIR	127/220(50)	
Mongolia	D	None	SECAM	None	SECAM	OIRT(R)	None	220(50)	

	CCIR System		Color System		Satellite Service Standard	Channelization			
Country	VHF	UHF	VHF	UHF		VHF	UHF	Voltage	Remarks
Morocco	B	None	SECAM	None	SECAM	Unique	None	127/220(50)	
Mozambique	B	None	PAL	None		CCIR	None	220(50)	
Nauru								220(50)	No TV
Nepal								220(50)	No TV
Netherland Antilles		M	None	NTSC	None	USA	None	127/220(50)(60)	
New Caledonia	K'	None	SECAM	None		FOT.	None	220(50)	
New Zealand	B	None	PAL	None	PAL	Unique	None	230/400(50)	
Nicaragua	M	None	NTSC	None		USA	None	120(60)	
Niger	K'	None	SECAM	None	SECAM	FOT.	None	220/380(50)	
Nigeria	B	G	PAL	PAL	PAL	CCIR	CCIR	230/400(50)	
North Mariana Island		M	None	NTSC	None	USA	None	110/220(60)	
Namibia	I	None	PAL	None		Unique	None	220(50)	
Norway	B	G	PAL	PAL	PAL	CCIR	CCIR	230(50)	
Oman	B	G	PAL	PAL	PAL	CCIR	CCIR	220(50)	
Pakistan	B	None	PAL	None		CCIR	None	230/400(50)	
Panama	M	None	NTSC	None		USA	None	110/115/120/126(60)	
Papua New Guinea								240/415(50)	
Paraguay	N	None	PAL	None		CCIR	None	220(50)	
People's Republic of China			D	None	PAL	Unique	None	220(50)	
Peru	M	None	NTSC	None	NTSC	USA	None	220(60)	
Philippines	M	None	NTSC	None	NTSC	USA	None	110/220(60)	
Poland	D	K	SECAM	SECAM	SECAM	OIRT(E)	CCIR	220/380(50)	
Portugal	B	G	PAL	PAL	PAL	CCIR	CCIR	220/380(50)	
Puerto Rico	M	None	NTSC	None		USA	None	120(60)	
Qatar	B	None	PAL	None		CCIR	None	220(50)	
Reunion	K'	None	SECAM	None		Fot U.	None	220(50)	
Romania	D	None	None	None		OIRT(R)	None	220(50)	
Russia	D	K	SECAM	SECAM		OIRT(R)	CCIR	127/220(50)	
Rwanda								220(50)	No TV
Sabah								220(50)	No TV
Samoa-American	M	None	NTSC	None		USA	None	230(50)	
Sarawak	B	None	PAL	None		CCIR	None	220(50)	
Saudi Arabia	B	G	SECAM	SECAM	SECAM	CCIR	CCIR	127/220/380(50)(60)	
Senegal	K'	None	SECAM	None		FOT U.	None	127/220(50)	
Seychelles	B	None	PAL	None		CCIR	None	230(50)	
Sierra Leone	B	None	PAL	None		CCIR	None	230(50)	
Singapore	B	None	PAL	None		CCIR	None	230/400(50)	
Society Islands	K'	None	None	None		FOT.	None	240(50)	
Somalia								230(50)	No TV
South Africa	I	None	PAL	None	PAL	Unique	None	220/380(50)	
South West Africa								220/380(50)	No TV
Spain	B	G	PAL	PAL	PAL	CCIR	CCIR	127/220/380(50)	

	CCIR System		Color System		Satellite Service Standard	Channelization			
Country	VHF	UHF	VHF	UHF		VHF	UHF	Voltage	Remarks
Sri Lanka	B	None	PAL	None		CCIR	None	230(50)	
St. Kitts	M	None	NTSC	None		USA	None	220(60)	
St. Lucia								440(50)	No TV
St. Pierre	K'	None	SECAM	None		FOT U.	None	220(50)	
Sudan	B	None	None	None	PAL	CCIR	None	240(50)	
Surinam	M	None	NTSC	None		USA	None	110/115/127/220(60)	
Swaziland	B	G	PAL	PAL	PAL	CCIR	CCIR	230(50)	
Sweden	B	G	PAL	PAL	PAL	CCIR	CCIr	220/380(50)	
Switzerland	B	G	PAL	PAL		CCIR	CCIR	220/380(50)	
Syria	B	None	SECAM	None		CCIR	None	115/200(50)	
Tahiti	K'	None	SECAM	none	SECAM	FOT U.	None	127(60)	
Taiwan	M	None	NTSC	None		USA	None	110/200(60)	
Tanzania	B	None	PAL	None		CCIR	None	230/440(50)	
Thailand	B	None	PAL	None	PAL	CCIR	None	230/380(50)	
Trinidad and Tobago		M	None	NTSC	None	USA	None	115/230960)	
Togo	K'	None	SECAM	None		FOT U.	None	127/220(50)	
Tonga								230(50)	No TV
Tunisia	B	None	SECAM	None		CCIR	None	115/220/380(50)	
Turks & Caicos	M	None	NTSC	None		USA	None	110/220/440(60)	
Turkey	B	None	PAL	None	PAL	CCIR	None	220/380(50)	
Turkey-Cyprus	B	G	PAL	PAL	PAL	CCIR	CCIR	220/380(50)	
Uganda	B	None	PAL	None		CCIR	None	240/415(50)	
UAE	G		PAL		CCIR	CCIR		220(50)	
United Kingdom	A	I	PAL	PAL	PAL	Unique	CCIR	240/415(50)	
United States	M	M	NTSC	NTSC	NTSC	USA	USA	110/220(60)	
Upper Volta	K'	None	None	None		FOT U.	None	220/380(50)	
Uraguay	N	None	PAL	None		CCIR	None	220(50)	
Venezuela	M	None	PAL	None	NTSC	USA	None	120/240(60)	
Vietnam	D	None	SECAM	None	SECAM	OIRT(R)	None	120/127/230(50)	
Virgin Islands(U.S.)		M	None	NTSC	None	USA	None	110(60)	
Virgin Islands(U.K.)		M	None	NTSC	None	USA	None	110(60)	
Wake Island	M	None	NTSC	None		USA	None	110/220(60)	
Yemen-South	B	None	PAL	None		CCIR	None	230(50)	
Yemen-North	B	None	NTSC	None		CCIR	None	230(50)	
Yugoslavia	B	H	PAL	PAL	PAL	CCIR	CCIR	220/380(50)	
Zaire	K'	None	SECAM	None	SECAM	FOT U.	None	220(50)	
Zambia	B	None	PAL	None		CCIR	None	220(50)	
Zimbabwe	B	None	None	None		CCIR	None	230/240(50)	

Appendix C

C- and Ku-band Satellite EIRP Margin-Above-Receiver Threshold Charts

The following C-band and Ku-band charts can be used to estimate the margin above or below the receiver's threshold level that will be achieved through various combinations of antennas and low noise amplifiers. The below chart assumes nominal values of antenna efficiency, free space loss between the satellite and the site location, and antenna elevation angle.

Table 1. Large Aperture C-band Earth Station Margin-above-Threshold Chart

Antenna:	3.9m (13 ft)			4.88m (16 ft)			6m (20 ft)			7.6m (25 ft)			10m (32.5 ft)		
LNB N.T.:	90°	60°	30°	90°	60°	30°	90°	60°	30°	90°	60°	30°	90°	60°	30°
EIRP															
34	+3.8	+5.2	+7.3	+5.6	+7.0	+9.1	+7.6	+9.0	+11.0	+9.5	+10.9	+13.0	+11.8	+13.2	+15.3
33	+2.8	+4.2	+6.3	+4.6	+6.0	+8.1	+6.6	+8.0	+10.0	+8.5	+9.9	+12.0	+10.8	+12.2	+14.3
32	+1.8	+3.2	+5.3	+3.6	+5.0	+7.1	+5.6	+7.0	+9.0	+7.5	+8.9	+11.0	+ 9.8	+11.2	+13.3
31	+0.8	+2.2	+4.3	+2.6	+4.0	+6.1	+4.6	+6.0	+8.0	+6.5	+7.9	+10.0	+ 8.8	+10.2	+12.3
30	-0.2	+1.2	+3.3	+1.6	+3.0	+5.1	+3.6	+5.0	+7.0	+5.5	+6.9	+9.0	+ 7.8	+9.2	+11.3
29	-1.2	+0.2	+2.3	+0.6	+2.0	+4.1	+2.6	+4.0	+6.0	+4.5	+5.9	+8.0	+ 6.8	+8.2	+10.3
28	-2.2	-0.8	+1.3	-0.4	+1.0	+3.1	+1.6	+3.0	+5.0	+3.5	+4.9	+7.0	+ 5.8	+7.2	+ 0.3
27	-3.2	-1.8	+0.3	-1.4	0.0	+2.1	+0.6	+2.0	+4.0	+2.5	+3.9	+6.0	+ 4.8	+6.2	+ 8.3
26	-4.2	-2.8	-0.7	-2.4	-1.0	+1.1	-0.4	+1.0	+3.0	+1.5	+2.9	+5.0	+ 3.8	+5.2	+ 7.3
25	-5.2	-3.8	-1.7	-3.4	-2.0	+0.1	-1.4	0.0	+2.0	+0.5	+1.9	+4.0	+ 2.8	+4.2	+ 6.3
24	-6.2	-4.8	-2.7	-4.4	-3.0	-0.9	-2.4	-1.0	+1.0	-0.5	+0.9	+3.0	+ 1.8	+3.2	+ 5.3
23		-5.8	-3.7	-5.4	-4.0	-1.9	-3.4	-2.0	0.0	-1.5	-0.1	+2.0	+ 0.8	+2.2	+ 4.3
22		-6.8	-4.7	-6.4	-5.0	-2.9	-4.4	-3.0	-1.0	-2.5	-1.1	+1.0	- 0.2	+1.2	+ 3.3
21			-5.7		-6.0	-3.9	-5.5	-4.0	-2.0	-3.5	-2.1	0.0	- 1.0	+0.2	+ 2.3
20			-6.7		-7.0	-4.9	-6.4	-5.0	-3.0	-4.5	-3.1	-1.0	- 2.0	-0.8	+ 1.3
19						-5.9		-6.0	-4.0	-5.5	-4.1	-2.0	- 3.0	-2.8	+ 0.3
18						-6.9		-7.0	-5.0	-6.5	-5.1	-3.0	- 4.0	-3.8	- 0.7
17									-6.0		-6.1	-4.0	- 5.0	-2.8	- 1.7
16									-7.0		-7.1	-5.0	- 6.0	-3.8	- 2.7

Table 2. Small Aperture C-band Earth Station Margin-above-Threshold Chart

Antenna:	1.2m (4 ft)			1.8m (6 ft)			2.4 (8 ft)			3.0 (10 ft)		
LNB N.T.:	90°	60°	30°	90°	60°	30°	90°	60°	30°	90°	60°	30°
EIRP												
40	- 0.4	+1.0	+3.1	+3.1	+4.5	+6.6	+5.6	+7.0	+9.1	+7.6	+8.9	+11.0
39	- 1.4	+0.0	+2.1	+2.1	+3.5	+5.6	+4.6	+6.0	+8.1	+6.6	+7.9	+10.0
38	- 2.4	- 1.0	+1.1	+1.1	+2.5	+4.6	+3.6	+5.0	+7.1	+5.6	+6.9	+ 9.0
37	- 3.4	- 2.0	+0.1	+0.1	+1.5	+3.6	+2.6	+4.0	+6.1	+4.6	+5.9	+ 8.0
36	- 4.4	- 3.0	- 0.9	- 0.9	+0.5	+2.6	+1.6	+3.0	+5.1	+3.6	+4.9	+7.0
35	- 5.4	- 4.0	- 1.9	- 1.9	- 0.5	+1.6	+0.6	+2.0	+4.1	+2.6	+3.9	+6.0
34	- 6.4	- 5.0	- 2.9	- 2.9	- 1.5	+0.6	- 0.4	+1.0	+3.1	+1.6	+2.9	+5.0
33		- 6.0	- 3.9	- 3.9	- 2.5	- 0.4	- 1.4	+0.0	+2.1	+0.6	+1.9	+4.0
32		- 7.0	- 4.9	- 4.9	- 3.5	- 1.4	- 2.4	- 1.0	+1.1	- 0.4	+0.9	+3.0
31			- 5.9	- 5.9	- 4.5	- 2.4	- 3.4	-2.0	+0.1	- 1.4	- 0.1	+2.0
30			- 6.9	- 6.9	- 5.5	- 3.4	- 4.4	- 3.0	- 0.9	- 2.4	- 1.1	+1.0
29					- 6.5	- 4.4	- 5.4	- 4.0	- 1.9	- 3.4	- 2.1	+0.0
28						- 5.4	- 6.4	- 5.0	- 2.9	- 4.4	- 3.1	- 1.0
27						- 6.4		- 6.0	- 3.9	- 5.4	- 4.1	- 2.0
26								- 7.0	- 4.9	- 6.4	- 5.1	- 3.0
25									- 5.9		- 6.1	- 4.0
24									- 6.9			- 5.0
23												- 6.0
22												- 7.0

System Noise Power

Any amount of noise that is added to our incoming microwaves can degrade the performance of the system by reducing the carrier-to-noise ratio (C/NR) of the satellite signal. The three main contributors of noise are the receiving antenna, the LNA and the satellite receiver. Every satellite antenna intercepts a certain amount of noise along with the intended signal. The noise temperature of the antenna varies with the elevation angle of the dish. Since the Earth itself has a noise temperature of 290 degrees Kelvin, the lower the elevation angle of the antenna the greater the amount of earth noise that the dish will pick up. The exact amount of noise depends on the distribution of the antenna's sidelobes, the type of feed in use, and other factors. However, we can approximate the noise temperature for a given antenna elevation angle with the following formula:

Noise temperature = 14 + (180/antenna elevation in degrees)

Antenna noise temperature when positioned at a 60 degree elevation angle would be approximately 17 degrees Kelvin; when positioned at a 10 degree elevation angle would be approximately 32 degrees Kelvin.

Receiver Threshold

One of the most important specifications for any satellite video receiver is its "threshold point." Receiver threshold is expressed in C/NR and is the point at which the linear relationship between the C/NR of the incoming satellite

Table 3. Ku-band Earth Station Margin-above-threshold Chart—Small aperture antennas.

Antenna:	0.61m	(2 ft)	1.2m	(4 ft)	1.8m	(6 ft)	2.4m	(8 ft)	3m	(10 ft)
LNB N.T.: (in K)	220°	90°	220°	90°	220°	90°	220°	90°	220°	90°
LNB N.F.: (in dB)	2.5	1.2	2.5	1.2	2.5	1.2	2.5	1.2	2.5	1.2
EIRP in dBW										
55	+5.2	+8.6	+11.2	+14.6	+14.7	+18.1	+17.2	+20.6	+19.1	+22.6
54	+4.2	+7.6	+10.2	+13.6	+13.7	+17.1	+16.2	+19.6	+18.1	+21.6
53	+3.2	+6.6	+ 9.2	+12.6	+12.7	+16.1	+15.2	+18.6	+17.1	+20.6
52	+2.2	+5.6	+ 8.2	+11.6	+11.7	+15.1	+14.2	+17.6	+16.1	+19.6
51	+1.2	+4.6	+ 7.2	+10.6	+10.7	+14.1	+13.2	+16.6	+15.1	+18.6
50	+0.2	+3.6	+ 6.2	+ 9.6	+ 9.7	+13.1	+12.2	+15.6	+14.1	+17.6
49	- 0.8	+2.6	+ 5.2	+ 8.6	+ 8.7	+12.1	+11.2	+14.6	+13.1	+16.6
48	- 1.8	+1.6	+ 4.2	+ 7.6	+ 7.7	+11.1	+10.2	+13.6	+12.1	+15.6
47	- 2.8	+0.6	+ 3.2	+ 6.6	+ 6.7	+10.1	+ 9.2	+12.6	+11.1	+14.6
46	- 3.8	- 0.4	+ 2.2	+ 5.6	+ 5.7	+ 9.1	+ 8.2	+11.6	+10.1	+13.6
45	- 4.8	- 1.4	+ 1.2	+ 4.6	+ 4.7	+ 8.1	+ 7.2	+10.6	+ 9.1	+12.6
44	- 5.8	- 2.4	+ 0.2	+ 3.6	+ 3.7	+ 7.1	+ 6.2	+ 9.6	+ 8.1	+11.6
43	- 6.8	- 3.4	- 0.8	+ 2.6	+ 2.7	+ 6.1	+ 5.2	+ 8.6	+ 7.1	+10.6
42		- 4.4	- 1.8	+ 1.6	+ 1.7	+ 5.1	+ 4.2	+ 7.6	+ 6.1	+ 9.6
41		- 5.4	- 2.8	+ 0.6	+ 0.7	+ 4.1	+ 3.2	+ 6.6	+ 5.1	+ 8.6
40		- 6.4	- 3.8	- 0.4	- 1.7	+ 3.1	+ 2.2	+ 5.6	+ 4.1	+ 7.6
39			- 4.8	- 1.4	- 2.7	+ 2.1	+ 1.2	+ 4.6	+ 3.1	+ 6.6
38			- 5.8	- 2.4	- 3.7	+ 1.1	+ 0.2	+ 3.6	+ 2.1	+ 5.6
37			- 6.8	- 3.4	- 4.7	+ 0.1	- 0.8	+ 2.6	+ 1.1	+ 4.6
36				- 4.4	- 5.7	- 0.9	- 1.8	+ 1.6	+ 0.1	+ 3.6
35				- 5.4	- 6.7	- 1.9	- 2.8	+ 0.6	- 0.9	+ 2.6
34				- 6.4		- 2.9	- 3.8	- 0.4	- 1.9	+ 1.6
33						- 3.9	- 4.8	- 1.4	- 2.9	+ 0.6
32						- 4.9	- 5.8	- 2.4	- 3.9	- 0.4
31						- 5.9	- 6.8	- 3.4	- 4.9	- 1.4
30								- 4.4	- 5.9	- 2.4

signal and the S/NR (Signal-to-noise ratio) of the demodulated video signal breaks down. As the C/NR of the incoming satellite signal falls below the receiver's threshold point, the quality of the corresponding video signal becomes increasingly noisy. When the C/NR of the incoming satellite signal is approximately the same as the C/NR threshold rating of the receiver, the video is relatively clear with a minimum of impulse noise or "sparklies." Once the C/NR of the incoming satellite signal reaches +2 or more dB above the threshold rating of the receiver, the last few stray sparklies disappear and the video appears to be totally clear.

Most of the home satellite TV receivers that are available today have a threshold rating of 8 dB C/NR. A few of the better receivers may even achieve a superior threshold of 7 dB C/NR. The lower the threshold point of the receiver the better, because the C/NR of the incoming signal can then be even lower and yet the system can still achieve an acceptable quality of video

Table 3. Ku-band Margin-above-threshold Chart—Large Aperture Antennas

Antenna:	3.9m (13 ft)		4.88m (16 ft)		6m (20 ft)		7.6m (25 ft)		10m (32.5 ft)	
LNB N.T.: (in K)	220°	90°	220°	90°	220°	90°	220°	90°	220°	90°
LNB N.F.:	2.5	1.2	2.5	1.2	2.5	1.2	2.5	1.2	2.5	1.2
EIRP in dBW										
45	+11.4	+14.8	+13.2	+16.6	+15.1	+18.6	+17.1	+20.5	+19.4	+22.8
44	+10.4	+13.8	+12.2	+15.6	+14.1	+17.6	+16.1	+19.5	+18.4	+21.8
43	+ 9.4	+12.8	+11.2	+14.6	+13.1	+16.6	+15.1	+18.5	+17.4	+20.8
42	+ 8.4	+11.8	+10.2	+13.6	+12.1	+15.6	+14.1	+17.5	+16.4	+19.8
41	+ 7.4	+10.8	+ 9.2	+12.6	+11.1	+14.6	+13.1	+16.5	+15.4	+18.8
40	+ 6.4	+ 9.8	+ 8.2	+11.6	+10.1	+13.6	+12.1	+15.5	+14.4	+17.8
39	+ 5.4	+ 8.8	+ 7.2	+10.6	+ 9.1	+12.6	+11.1	+14.5	+13.4	+16.8
38	+ 4.4	+ 7.8	+ 6.2	+ 9.6	+ 8.1	+11.6	+10.1	+13.5	+12.4	+15.8
37	+ 3.4	+ 6.8	+ 5.2	+ 8.6	+ 7.1	+10.6	+ 9.1	+12.5	+11.4	+14.8
36	+ 2.4	+ 5.8	+ 4.2	+ 7.6	+ 6.1	+ 9.6	+ 8.1	+11.5	+10.4	+13.8
35	+ 1.4	+ 4.8	+ 3.2	+ 6.6	+ 5.1	+ 8.6	+ 7.1	+10.5	+ 9.4	+12.8
34	+ 0.4	+ 3.8	+ 2.2	+ 5.6	+ 4.1	+ 7.6	+ 6.1	+ 9.5	+ 8.4	+11.8
33	- 0.6	+ 2.8	+ 1.2	+ 4.6	+ 3.1	+ 6.6	+ 5.1	+ 8.5	+ 7.4	+10.8
32	- 1.6	+ 1.8	+ 0.2	+ 3.6	+ 2.1	+ 5.6	+ 4.1	+ 7.5	+ 6.4	+ 9.8
31	- 2.6	+ 0.8	- 0.8	+ 2.6	+ 1.1	+ 4.6	+ 3.1	+ 6.5	+ 5.4	+ 8.8
30	- 3.6	- 0.2	- 1.8	+ 1.6	+ 0.1	+ 3.6	+ 2.1	+ 5.5	+ 4.4	+ 7.8
29	- 4.6	- 1.2	- 2.8	+ 0.6	- 0.9	+ 2.6	+ 1.1	+ 4.5	+ 3.4	+ 6.8
28	- 5.6	- 2.2	- 3.8	- 0.4	- 1.9	+ 1.6	+ 0.1	+ 3.5	+ 2.4	+ 5.8
27	- 6.6	- 3.2	- 4.8	- 1.4	- 2.9	+ 0.6	- 0.9	+ 2.5	+ 1.4	+ 4.8
26		- 4.2	- 5.8	- 2.4	- 3.9	- 0.4	- 1.9	+ 1.5	+ 0.4	+ 3.8
25		- 5.2	- 6.8	- 3.4	- 4.9	- 1.4	- 2.9	+ 0.5	- 0.6	+ 2.8

reception.

Ideally, the satellite receiver should attain a "margin" of at least +4 dB above receiver threshold: 2 dB to eliminate the last stray sparklies and an additional +2 dB to offset against the possibility of signal that often occurs as the satellite's TWTAs age over time. With Ku-band systems, an additional margin of several more dB is usually desirable as a way to minimize the attenuation of the signal that is caused by heavy rainfall. The amount of Ku-band margin selected will vary according to the rain rate level normally experienced within the region where the earth station is to be installed.

A certain combination of TVRO components cannot produce the required margin above threshold. The only recourse is to use either a larger, higher gain receiving antenna, a lower noise temperature LNB, a receiver that possesses a lower threshold level or various combinations thereof to achieve the desired results.

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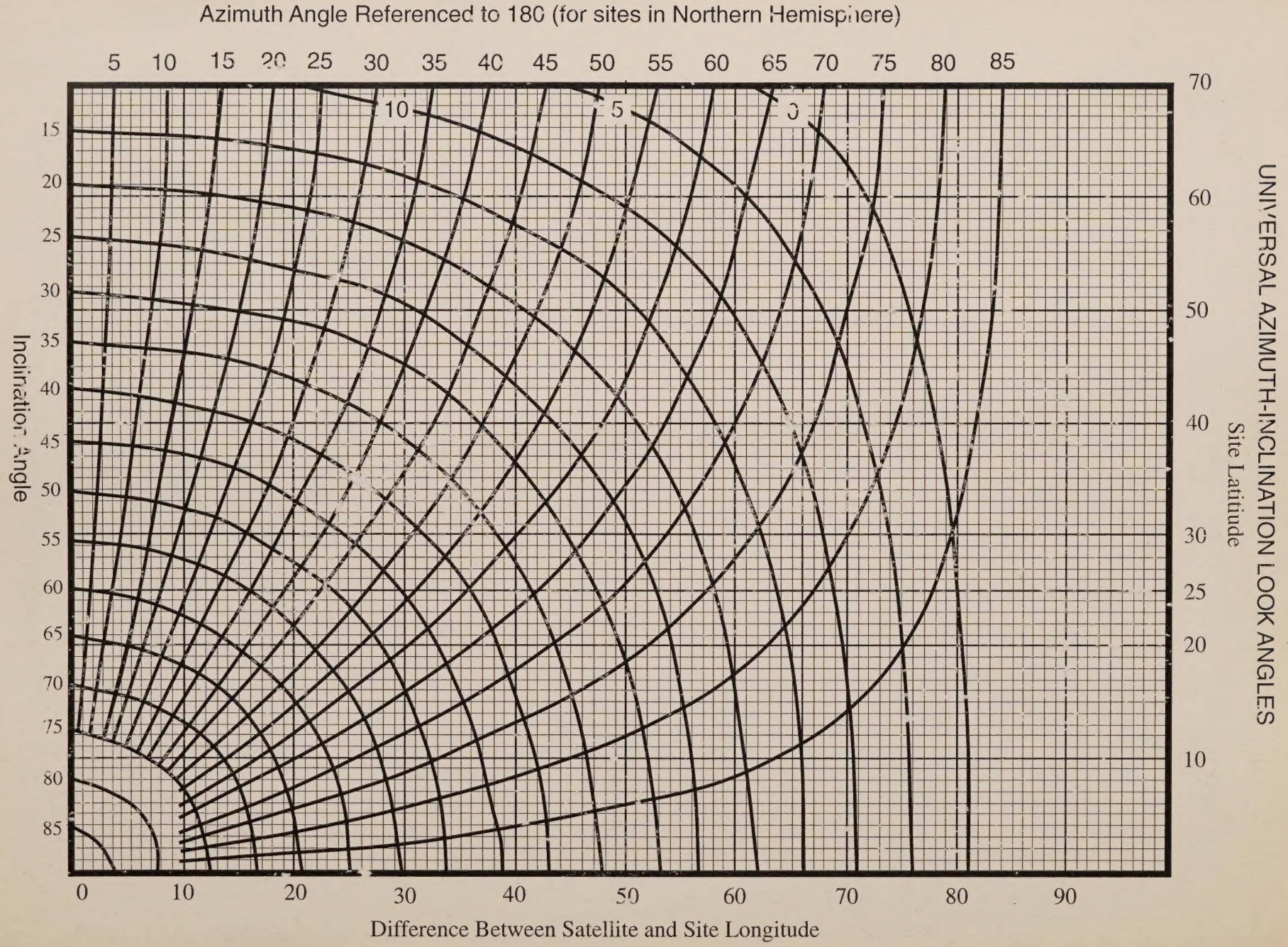
Azimuth Angle Referenced to 180 (for sites in Northern Hemisphere)
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85
10
5
0
15 20 25 30 35 40 45 50 55 60 65 70 75 80 85
Inclination Angle
70 60 50 40 30 25 20 10
Site Latitude
UNIVERSAL AZIMUTH-INCLINATION LOOK ANGLES
0 10 20 30 40 50 60 70 80 90
Difference Between Satellite and Site Longitude